SUMMARY REPORT

A SUMMARY OF CUHP RE-CALIBRATION EFFORTS

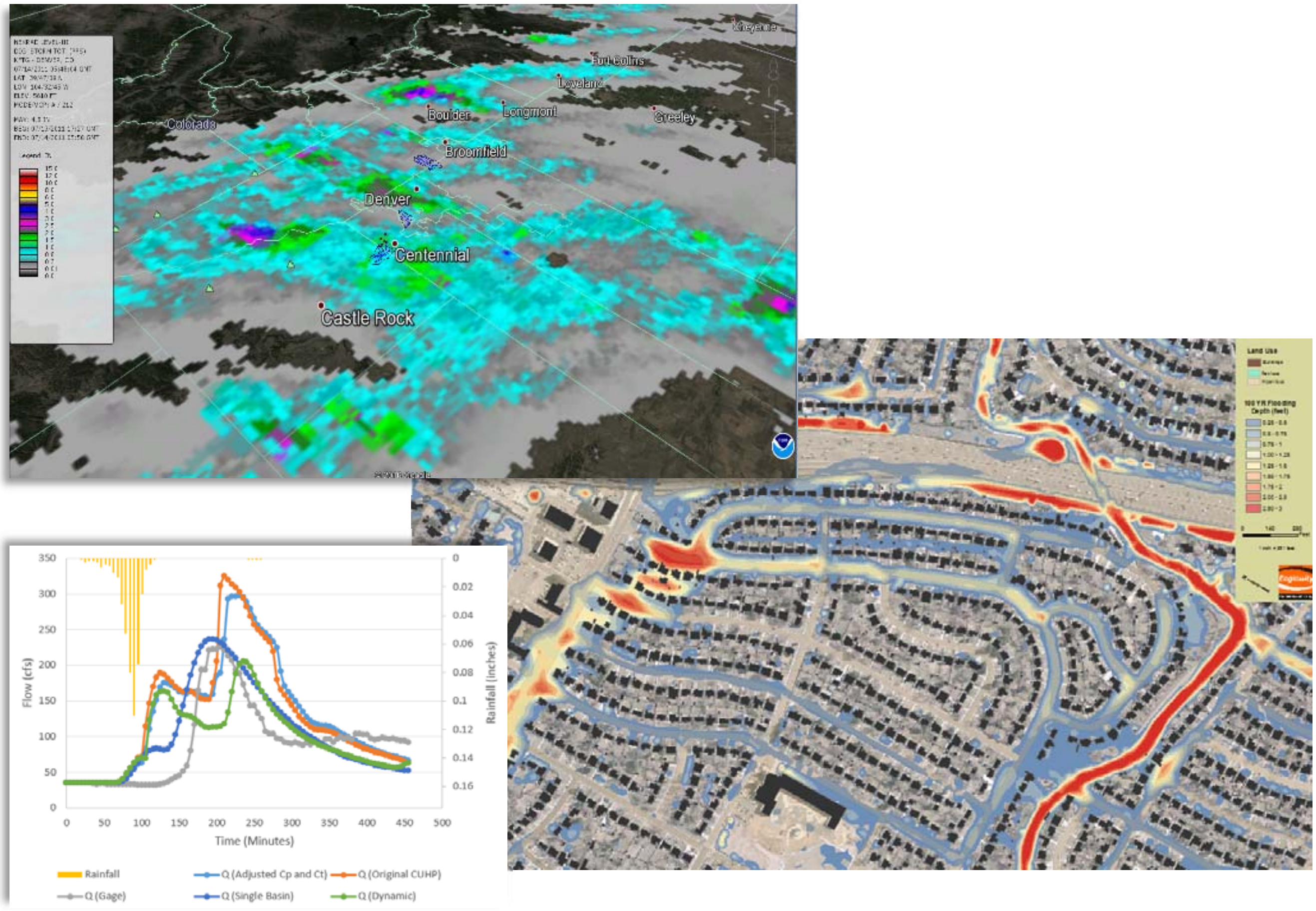

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TABLE OF CONTENTS

TABLES

FIGURES

Appendices

Appendix A – GARR Rainfall Hyetographs

Appendix B – CUHP Sub-Catchment Parameters for Select Basins (Digital Appendix not Included in Report)

Appendix C – Addressed Comments from June 2016 Draft Summary Report

EXECUTIVE SUMMARY

This summary report highlights the efforts to re-calibrate the Colorado Urban Hydrograph Procedure (CUHP) in 2015 and 2016. This effort was commissioned by the Urban Drainage and Flood Control District (UDFCD) as a result of noting higher than anticipated peak flow values during the Major Drainageway Planning (MDP) and Outfall Systems Planning (OSP) hydrologic studies currently underway and also ones that were performed in the past. The CUHP had not been calibrated with gage data since its inception and peak flows developed in recent studies deviated from statistical gage analysis across the District.

The calibration effort utilized Gage Adjusted Radar Rainfall and recorded runoff from US Geological Survey (USGS) and Alert 5 Gages in addition to statistical gage analysis to adjust CUHP's timing and peaking coefficients to be more in line with the large gage record maintained by the District and the USGS. The iterative approach between matching recorded runoff and gage values developed the *Proposed Version of CUHP* presented within this report.

Changes to CUHP proposed within this report will lower peak flow rates for almost all studies across the District. However, as shown through comparison of gage frequency analysis, values produced with the proposed version of CUHP will still be conservative when compared to most gage frequency estimates. Work performed though calibration found that CUHP Version 1.4.4 is statistically within range of recorded rainfall and runoff. However, Version 1.4.4 more often produced results higher than the recorded flow when compared to the proposed version of CUHP. Additionally, the proposed version of CUHP will trend more closely with gage frequency estimates than Version 1.4.4. In order to match both recorded rainfall and runoff values and gage frequency estimates, the most recently published 1 hour precipitation depths found in NOAA's Atlas 14 Precipitation Frequency Estimates are recommended.

BACKGROUND AND INTRODUCTION

CUHP Background

The Colorado Urban Hydrograph Procedure (CUHP) was first developed by the Urban Drainage and Flood Control District (UDFCD) in 1971. CUHP is an evolution of the Snyder Unit Hydrograph (Snyder 1938) that has been modified to include imperviousness, making it an Urban Unit Hydrograph that accounts for a watershed's imperviousness percentage, slope, and size. CUHP translates a watershed's response from rainfall into a runoff hydrograph that reflects peak runoff rates, volumes, and timing. The complete history of CUHP is presented within the CUHP 2005 User Manual (UDFCD 2014). Many adjustments to CUHP have been made in the past. One of the more recent and influential adjustments that exist within CUHP are modifications of timing coefficients for basins less than 160 acres (Guo and Urbonas 2008). These modifications connected a disparity between 90 and 100 acres that occurred when CUHP 2005 was developed.

Hydrograph Routing

Hydrographs developed from CUHP are routed within the Storm Water Management Model (SWMM5)(EPA 2010) via the Kinematic Wave routing method. The Kinematic Wave is a shortened version of the St. Venant Equations, which are widely accepted as the governing equations in hydraulics to solve for momentum and continuity under shallow water approximations (Sturm 2010). The Kinematic Wave assumes that the flow is uniform and the friction slope of the water's surface is approximately equal to the channel slope. Under this assumption, Kinematic Wave hydraulics do not account for channel storage, flow attenuation, or backwater from downstream influences. The Kinematic Wave progresses a flood wave from upstream to downstream with no attenuation and only translates the wave in time. Some research has shown that the Kinematic Wave is accurate with Froude numbers as high as 2.0 (Woolhiser and Liggett 1967)(Liggett and Cunge 1975). Since natural channels do not flow supercritical[1] and that the Kinematic Wave velocity is less than the Dynamic Wave velocity, it has been suggested that the Kinematic Wave best represents a flood wave in natural channels. However, almost all research on Kinematic Wave velocity and applications is limited to shallow overland flow and generally does not address full channel hydraulics. Many publications recommend

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[1] Supercritical flow is defined when the Froude Number is greater than 1.0

the full solution of momentum (i.e. Dynamic Wave) be applied whenever the lateral inflow is less than the main channel flow (USGS 1984)(Liggett and Cunge 1975)(Ferrick and Goodman 1998). In practice, all forms of the St. Venant Equations (Kinematic, Diffusive, and Dynamic) are considered acceptable for channel routing.

Unit Discharge for Large and Small Watersheds

As with many runoff simulation models, the unit discharge of peak flow per runoff area of smaller basins is higher than larger basins within CUHP (See Figure 1). This phenomenon is observed in physical runoff models, regression equations, and unit hydrographs and represents physical routing characteristics that occur as flow progresses through the watershed. Larger drainage areas have a longer flow path and consequently more flow attenuation occurs before the drainage outlet while smaller watersheds have a shorter flow path and less flow attenuation.

CUHP was originally calibrated to single basins ranging from 0.15 to 3.08 square miles with a majority of the basins being larger than 0.3 square miles (192 acres). This is because most stream gages are located lower in the watershed. Over the years, however, CUHP has more widely been applied by subdivided one large watershed into many catchments averaging 90-100 acres in size. Since CUHP's hydrographs are routed via the Kinematic Wave, there is no attenuation of the flood hydrographs as they progress downstream. This, among other factors, has resulted in excessively high peak flows at drainage outlets for many of UDFCD's studies.

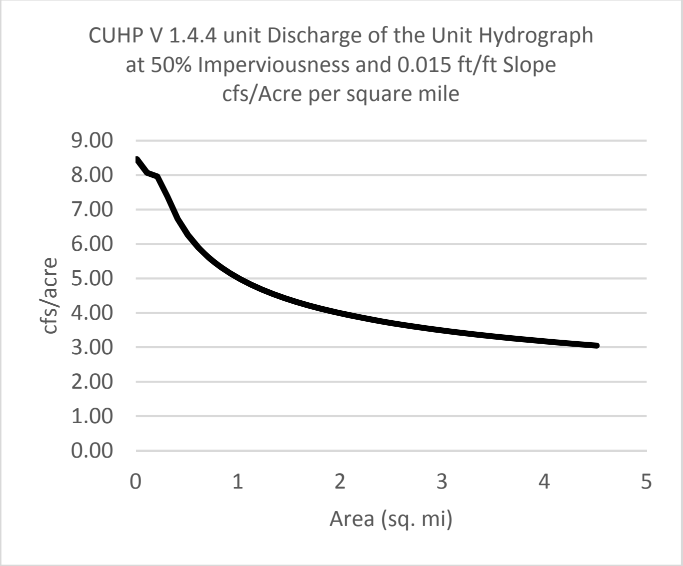

Figure 1 – Unit Discharge per Area of CUHP 1.4.4

The phenomenon of higher peaks from discretized drainage areas is not new and has been known for a long time (Dankenbring and Mays 2009). In 2014, Urbonas and Rapp (2014) published a report developing protocols for consistency in CUHP/SWMM hydrology for large discretized catchments. Recommendations within this report include modeling a more realistic drainage system that accounts for the channel slope between drop structures and higher channel roughness values. Essentially, the results of these recommendations are forcing the hydrographs from CUHP to be translated in time so they don't compound on each other. Since the Kinematic Wave does not attenuate flows (Sturm 2001, USGS 1984) or account for channel storage, modifying the slope and roughness of a channel to change timing is the only option under the limited mathematics of the Kinematic Wave.

Basis for Re-Calibrating CUHP

Even with the modifications from Urbonas and Rapp (2014), the UDFCD was experiencing higher than anticipated peak flow values during the Major Drainageway Planning (MDP) and Outfall Systems Planning (OSP) processes that apply CUHP and SWMM5 for hydrologic studies. To remedy the high peak flows, each study had user-adjusted peaking and timing coefficients within CUHP to match either previous studies or to be more in line with a stream gage statistical frequency analysis. This created inconstancy across the District in how CUHP was applied and was also not consistent with the Federal Emergency Management Agency's (FEMA) acceptance of the CUHP method where CUHP is accepted under the default parameters in the model (FEMA 2016). The District began to investigate a wide range of published flows against the large stream gage network throughout the entire District and noticed that the published values in the MDP and OSP studies are not always consistent with the gage frequency analysis in the watersheds studied. UDFCD commissioned this calibration effort based on the following needs:

- CUHP had not been calibrated with gage data since its inception in the 1970's and adjustments in the 1980s.
- Current practice requires users to adjust Cp for almost all studies. This develops a *study specific* calibrated model and reduces consistency in hydrologic practice across the District.
- Peak flows developed in recent studies deviated from statistical gage analysis across the District and created uncertainty with CUHP model results for some studies.

Under this calibration effort the District considered many alternatives to address the differences noted between gage analysis and the MDP/OSP hydrologic studies. These alternatives included:

1. Keep CUHP in its current form and incorporate Depth Area Reduction Factors (DARFs) for smaller watersheds and adopt the new NOAA Rainfall Atlas No. 14 to determine 1 hour point precipitation depths.
2. Adopt the Stormwater Management Model (SWMM5) overland flow equations for hydrology and calibrate the smaller SWMM basins to larger CUHP basins for baseline hydrology (EPA 2010).
3. Accept 2D Rain on Grid Technology within FEMA Accepted 2D Hydrology models like the Gridded Surface and Subsurface Hydrologic Analysis Model (GSSHA) developed by the US Army Corps of Engineers (Downer et al 2006, Downer and Ogden 2004).

4. Apply the full and/or partial solutions of motion (Dynamic and Diffusive Wave) for routing CUHP flows hydrographs for all studies (USGS 1984) (USACE 2002).
5. develop larger sub basin area delineations for all major drainage studies to reduce the high unit discharge that is not attenuated when routed with the Kinematic Wave.
6. Recalibrate CUHP with updated rainfall and runoff data and frequency analysis from USGS and Alert 5 gage history. This alternative keeps the hydrologic practice within the District relatively the same.

This Summary Report only includes results of the alternative recommended and carried forward, which was to recalibrate CUHP with updated rainfall and runoff and then test the results against gage frequency and existing studies within the District.

CALIBRATION PROCESS

Adjustments to CUHP's peaking and timing coefficients were tested as part of the calibration effort. This calibration effort was separated into two phases: First, CUHP was re-tested with Gage Adjusted Radar Rainfall (GARR)[2] and recorded runoff from USGS and Alert 5 Gages. Secondly, those adjustments were then tested with frequency design storms and statistical gage analysis. An iterative approach between matching recorded runoff and gage values developed the *Proposed Version of CUHP* ***(Proposed CUHP)***. This iterative approach first made an adjustment to the equations within CUHP that matched recorded runoff, then they were compared with frequency curves for gages that monitor clean[3], developed basins that have little to no detention or storage. The equations were then calibrated until good agreements were achieved.

The proposed coefficients within this summary will reduce flows for almost all studies. However, some studies across the district currently report peak flow values that match well to the flow frequency analysis at the stream gage. Many of these studies have *study specific* adjusted parameters that were input into CUHP during the hydrology phase. To be cautious while moving forward, testing of those hydrologic models was

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[2] Gage-adjusted radar rainfall (GARR) is gridded rainfall at high spatial and temporal resolution. GARR is a combination of radar and rain gage data, that leverages the strength of both sensor measurements (Vieux, 2013). It was produced by Vieux & Associates, Inc. for the Urban Drainage and Flood Control District for use in their flood warning program.

[3] Clean basins are described as Basins that have little effects from detention, diversions, and other anthropologic influences that could affect the frequency curve.

important to ensure that new calibrated peaking and timing parameters did not produce results below acceptable gage analysis.

PROPOSED ADJUSTMENTS

Although many various alternatives were tested, compared, and considered during this calibration process, the simplest and most effective path forward was to modify CUHP to match gage data and make limited changes to many of the other parameters. The following bullets support this decision:

- **No change to infiltration parameters**: Based upon review of many studies, published literature (Alley and Veenhuis 1983)(Arnold and Gibbons 1996)(Booth and Jackson 1997), and nationwide hydrologic guidance, it was found that the infiltration parameters within CUHP fall within an acceptable range for developed soils when it is considered that CUHP applies the time dependent form of Horton's Equation opposed to the integrated form which is used within distributed models such as SWMM5 and many other hydrologic models (Blackler 2013)(Blackler and Guo 2010). This study also found a low correlation between rainfall and runoff from Mountain Basins. All tests on the Mountain Basins found that CUHP infiltrated more rainfall than what was recorded at the gage. This will require further investigation that will be completed under a different project.
- **No change to design storm**: At this time, no changes to the design storm are proposed. However, this calibration considers the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 point precipitation frequency estimates for Denver and the surrounding areas. This study applied the updated NOAA 14 Atlas to calibrate CUHP so that it matches closely to both recorded flow and gage frequency analysis. It is therefore recommended to use the updated Atlas for all future studies.
- **No change to methodology**: CUHP follows the Snyder Unit Hydrograph Procedure (Snyder 1938)(Sherman 1932). This procedure was developed in 1938 and CUHP follows its general form with the addition of imperviousness to handle peaking for urban catchments. This commonly applied unit hydrograph procedure does not leave a lot of room for variation, as such, the general form of CUHP was held for this study.

Below are the adjustments to the Proposed CUHP:

Adjust Peaking Parameter (*P*) to be modified as Equations (1) and (2):

$$If\ Ia < 25\%, then\ P = 0.0006 * Ia^2 + 2.3 \tag{1}$$

$$If\ Ia > 25\%\ then\ P = -0.0005 * Ia^2 + 0.12 * Ia \tag{2}$$

Where, *Ia* is the percent imperviousness of the basin. Adjust the coefficient of peaking (C_P) to be Equations (3) and (4):

If the area is less than or equal to 120 acres, then:

$$C_p = P * C_T * 1.3 * A^{0.45} \tag{3}$$

For basins greater than 120 acres apply the following:

$$C_p = P * C_T * A^{0.30} \tag{4}$$

It was recommended to keep the timing coefficient for larger basins (C_T) as it is within the current CUHP. This study found that the timing remained appropriate for a majority of the basins tested. The above equations were tested for consistency on small and large basins to ensure smooth transitions between the equations applied for smaller and larger basins that are currently within CUHP. Figures 2 and 3 below present snapshots of this testing.

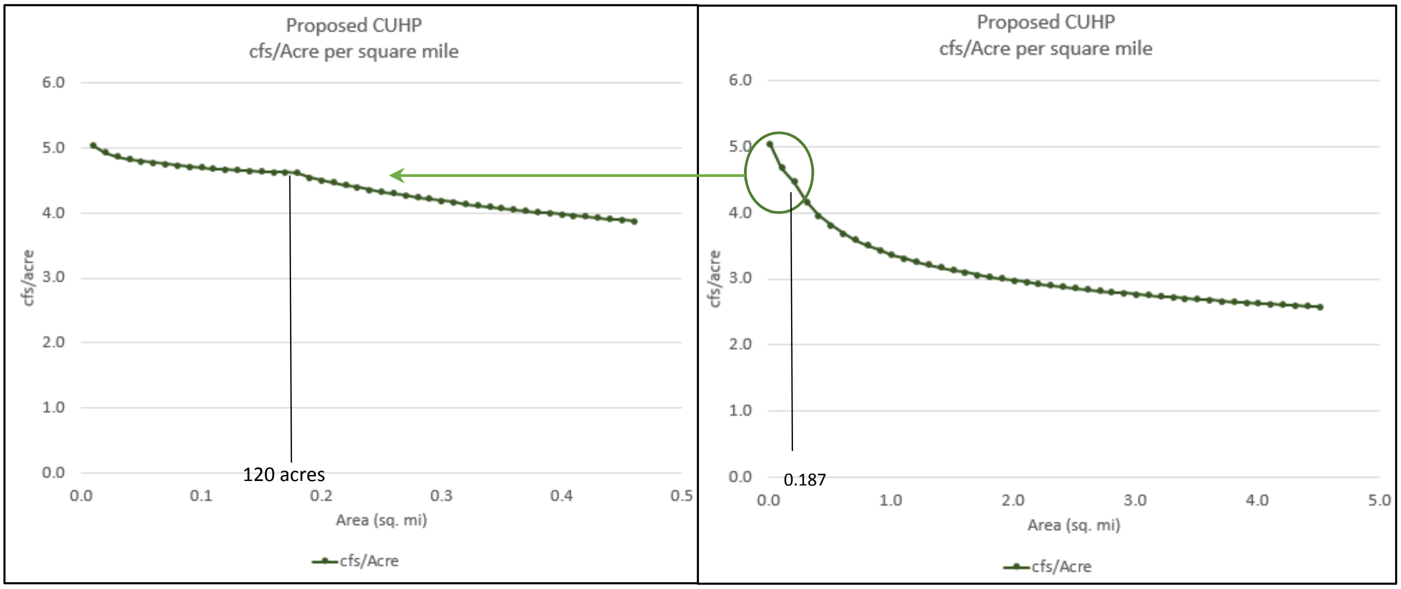


Figure 2 – Left: Proposed CUHP Unit Discharge for Basins 6 Acres up to 0.45 Square Miles, Right: Proposed CUHP Unit Discharge for Basins 6.4 acres to 4.5 square miles showing the smooth transition at 0.25 square miles.

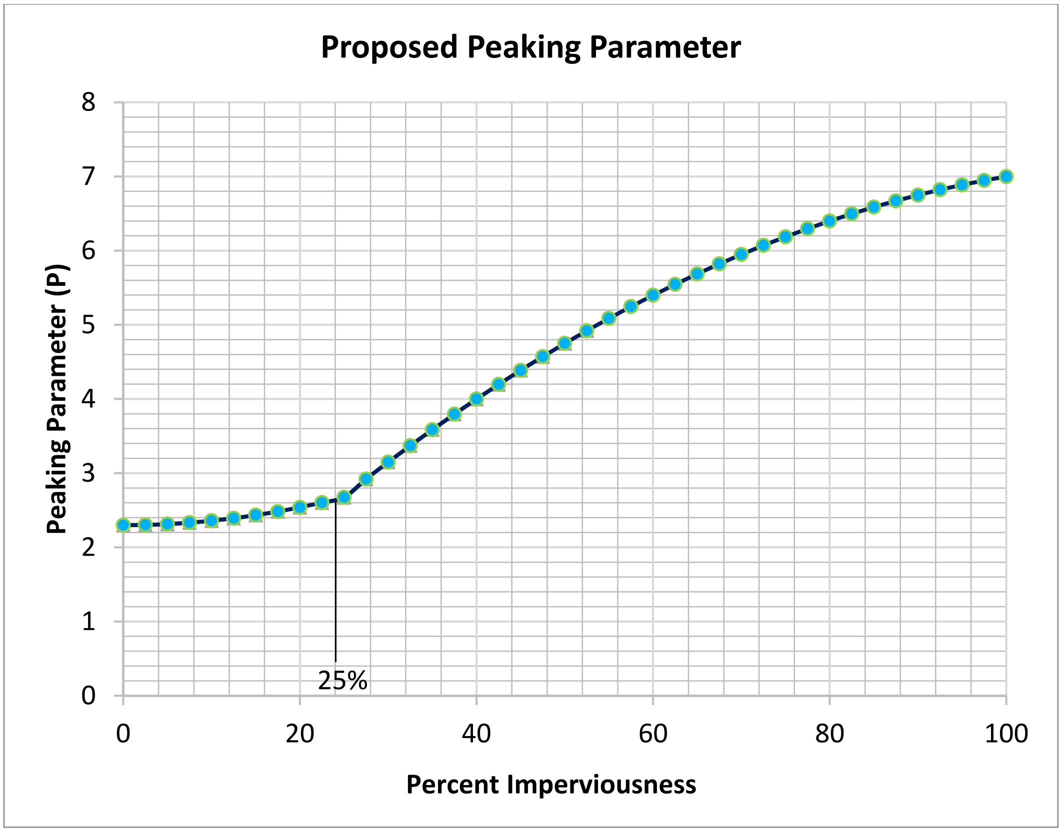


Figure 3 - Graph of the Peaking Parameter vs Imperviousness

COMPARISON OF RECORDED RAINFALL AND RUNOFF DATA

This analysis found that the Proposed CUHP has less error than CUHP 1.4.4 when compared to recorded rainfall from GARR and corresponding runoff from USGS and Alert 5 Gages for selected storms (See Table 2). Additionally, it found that CUHP 1.4.4 is more often higher than the Proposed CUHP (See Figure 5). Tables 1 and 2 below present a discussion of the basins tested during this analysis and the result of CUHP's performance when GARR storms were tested on select basins. Figure 4 below Tables 1 and 2 presents a graphical representation of the data sets.

Error testing followed guidance from the US Army Corps of Engineers Hydrologic Modeling System (HEC HMS) Manual, that defines error as

$$Z = 100\left|\frac{q_S(peak) - q_O(peak)}{q_O(peak)}\right| \qquad (5)$$

Where, Z is the absolute value of the difference between computed and observed flows expressed as a percentage, q_s is the computed peak flow from CUHP, q_o is the observed peak flow at the gage. This methodology treats overestimations and underestimations as equally undesirable. More discussion on error analysis for hydrologic systems is found within Chapter 9 of the HMS Technical Manual (Pages 97-100) (USACE 2000). It is also useful to know the average error being both above and below the gage results. At the bottom of Table 2 the row showing *Average (+/-)* includes the average of all error results when the absolute values in Equation 5 are ignored and error is both positive and negative. Numbers in this row that are positive indicate the average error is above the recorded values, or more simply put that the computed flows from CUHP are higher than the recorded flows at the gage.

Table 1 summarizes watershed and gage locations that were tested for calibration of the Proposed CUHP. Some gages did not have overlapping record with the GARR but did have a good length of annual peak flows that could be compared against the Proposed CUHP. These are described as gages "Tested for Frequency" in Table 1 below. An example would be North Sanderson Gulch, which did not have a gage record recent enough to compare with GARR storms, although results from the Proposed CUHP's 2- through 100-year results were compared with the gages prediction of the 2- through 100-year flows from a log Pearson III analysis.

Table 1 - Summary of Gages Tested as part of the Calibration Effort

Gage Description	**Tested for Calibration Version 1 (Yes/No)**	**Kept in Calibration Data Set (Yes/No)**	**Tested for Proposed CUHP Calibration (Yes/No)**	**Tested for Frequency (Yes/No)**	**Notes**
Dry Gulch	Yes	Yes	**Yes**	Yes	Updated MDP Model may have been completed while study was ongoing.
Dutch Creek	Yes	Yes	**Yes**	Yes	Storage in golf course upstream influences gage results. This storage is not accounted for in MDP model. Was added in calibration version 1 for testing.
Goldsmith	Yes	Yes	**Yes**	Yes	Good gage readings. Large watershed makes rainfall difficult to model. Upper and lower GARR storms created to better represent rainfall distribution.
Havana Pond	Yes	No	No	No	Calibrating to pond depths has less error for any storm due to the large change in volume over time compared to depth. Good agreement on calibration, but not viable to carry into data set.
Little Dry (Arapahoe County)	Yes	Yes	**Yes**	Yes	Good gage readings with little detention or piped systems since it is higher in the watershed.
Lena Gulch Upper	Yes	No	No	No	No success calibrating watersheds in the mountain basins during this phase.
Lena Gulch Lower	Yes	Yes	**Yes**	Yes	Reasonable gage. Upper Lena did not calibrate well but as it traveled through the developed areas more agreement was noted. Ponds immediately upstream have major influence on gage readings.
No Name at Quincy	Yes	No	No	*	Gage is located between pond and culvert, difficult to predict maintenance state and hydraulics.
North Sanderson Gulch at Lakewood	Yes	No	No	Yes	Gage record not current enough for GARR testing but a good gage for frequency testing as it represents a small, urbanized basin.

Gage Description	Tested for Calibration Version 1 (Yes/No)	Kept in Calibration Data Set (Yes/No)	Tested for Proposed CUHP Calibration (Yes/No)	Tested for Frequency (Yes/No)	Notes
Sanderson Gulch at Navajo	No	No	No	No	Gage record not long enough for frequency testing
Upper Harvard Gulch	Yes	Yes	**Yes**	Yes	Good gage with developed upper basin. 2D model shows Canal spilling, as such, canal spilling accounted for in runs.
Van Bibber at 93	Yes	No	No	*	No success calibrating watersheds in the mountain basins during this phase.
Harvard Gulch at Harvard Park	No	NA	NA	Yes	Good gage for frequency testing
Little Dry at Westminster	Considered	NA	NA	Yes	No time series available for GARR testing. Frequency testing only.
Weir Gulch	Considered	NA	NA	Yes	No time series available for GARR testing. Frequency testing only. Gage is un-reliable due to major leak in drop structure at gage.
Sloan’s Lake Trib	Considered	NA	NA	No	Gage is in pond. See Havana Pond Comments.
Westerly Creek	Considered	NA	NA	*	Gage does not have current record for GARR
Willow Creek	No	No	No	Yes	Frequency testing since MDP data fell within Gage data.

*Pending but Viable

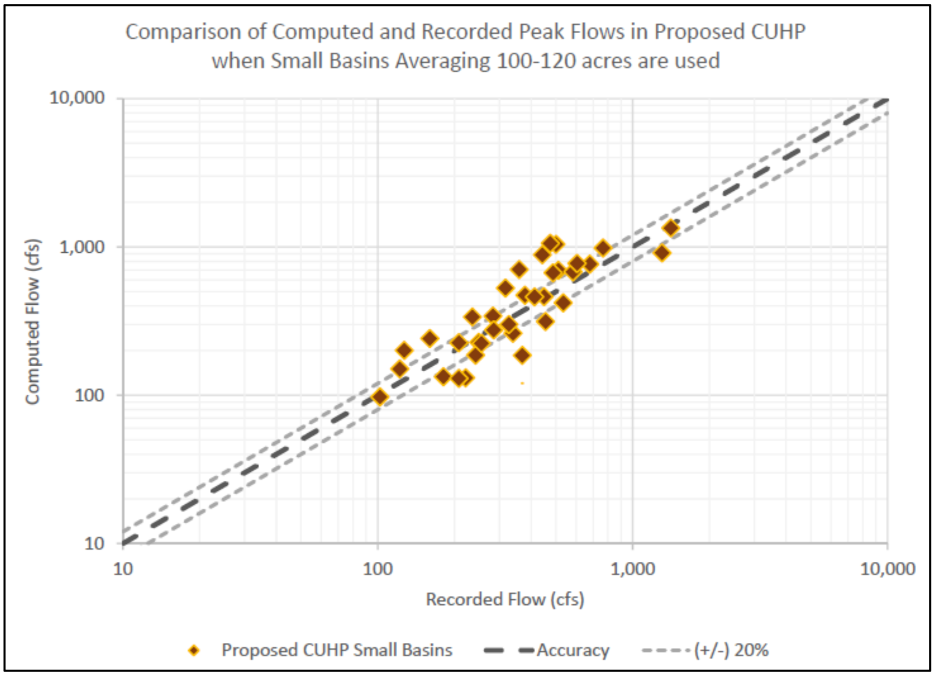
Table 2 – Summary of Recorded Rainfall and Runoff Testing between CUHP 1.4.4 and Proposed CUHP

Basin	Storm ID	Recorded Peak Flows	CUHP 1.4.4 Single Basin	CUHP 1.4.4 Small Basins	Proposed CUHP Single Basins	Proposed CUHP Small Basins	Total Depth (inches)	Peak 5 Minute Intensity (inch/hour)	Error (%) CUHP 1.4.4 Single Basin	Error (%) CUHP 1.4.4 Small Basins	Error (%) Proposed CUHP Single Basin	Error (%) Proposed CUHP Small Basins
Goldmsith	7/15/2013	1,303	1,192	1,181	973	911	0.93	2.64	9%	9%	25%	30%
Goldmsith	8/3/2013	235	499	424	417	338	0.63	2.36	112%	80%	77%	44%
Goldmsith	7/15/2014	765	1,413	1,257	1,343	982	0.93	3.27	85%	64%	76%	28%
Goldmsith	8/7/2014	221	264	170	244	131	0.26	0.90	19%	23%	10%	41%
Goldmsith	9/29/2014	500	1,424	1,386	1,146	1,042	1.22	3.55	185%	177%	129%	108%
Goldmsith	5/4/2015	249	426	269	363	227	0.52	1.23	71%	8%	46%	9%
Goldmsith	6/12/2015	1,412	1,960	1,642	1,702	1,343	1.80	2.00	39%	16%	21%	5%
Goldmsith	7/21/2015	359	760	565	630	705	0.65	1.79	112%	57%	76%	96%
Upper Harvard	7/13/2013	534	379	515	306	420	0.83	1.16	29%	4%	43%	21%
Upper Harvard	8/8/2013	511	650	929	492	696	0.75	2.30	27%	82%	4%	36%
Upper Harvard	5/20/2014	339	263	354	196	262	0.41	1.13	23%	4%	42%	23%
Upper Harvard	7/7/2014	449	388	607	340	462	0.58	1.98	14%	35%	24%	3%
Upper Harvard	9/29/2014	475	1,011	1,464	751	1,058	1.08	3.34	113%	208%	58%	123%
Upper Harvard	6/5/2015	367	519	149	92	120	0.74	0.80	41%	59%	75%	67%
Upper Harvard	6/11/2015	679	699	951	554	765	1.34	1.93	3%	40%	18%	13%
Upper Harvard	6/24/2015	583	625	889	514	679	0.53	1.77	7%	52%	12%	17%
Lena Gulch	7/13/2013	378	633	734	654	473	0.98	1.25	67%	94%	73%	25%
Lena Gulch	5/24/2014	455	372	490	394	314	0.71	1.22	18%	8%	13%	31%
Lena Gulch	7/30/2014	208	193	331	201	226	0.71	0.58	7%	59%	3%	9%
Lena Gulch	5/8/2015	302	145	214	155	102	0.73	0.60	52%	29%	49%	66%
Lena Gulch	6/11/2015	242	194	216	144	186	0.37	1.32	20%	11%	40%	23%
Dry Gulch	7/30/2014	127	221	213	178	201	0.80	0.46	74%	68%	40%	58%
Dry Gulch	5/7/2015	181	155	138	134	133	0.43	0.67	14%	24%	26%	26%
Dry Gulch	6/5/2015	208	152	131	133	130	0.40	1.97	27%	37%	36%	37%
Dry Gulch	6/12/2015	255	244	238	192	224	0.70	0.53	4%	7%	25%	12%
Dry Gulch	7/8/2015	102	105	104	88	97	0.37	0.31	3%	2%	14%	4%
Little Dry (arapahoe)	8/3/2013	327	323	379	249	300	0.55	1.39	1%	16%	24%	8%
Little Dry (arapahoe)	8/9/2013	283	351	420	278	342	0.59	1.30	24%	48%	2%	21%
Little Dry (arapahoe)	7/14/2014	442	993	1,189	726	885	0.84	3.43	125%	169%	64%	100%
Little Dry (arapahoe)	8/7/2014	285	324	365	236	276	0.42	2.23	14%	28%	17%	3%
Little Dry (arapahoe)	9/29/2014	369	237	246	168	186	0.35	1.57	36%	33%	54%	50%
Little Dry (arapahoe)	6/11/2015	605	484	922	398	775	1.39	1.37	20%	52%	34%	28%
Little Dry (arapahoe)	7/18/2015	122	183	193	135	150	0.33	1.33	50%	58%	11%	23%
Little Dry (arapahoe)	8/10/2015	487	707	799	568	669	0.90	1.69	45%	64%	17%	37%
Little Dry (arapahoe)	6/6/2016	317	559	630	445	529	0.80	1.43	76%	99%	40%	67%
Little Dry (arapahoe)	8/3/2016	160	267	307	203	242	0.41	1.20	67%	92%	27%	51%
Average of All Storms		412	536	584	437	461			30%	42%	6%	12%
								Geometric Mean of All Error (%)	27%	33%	27%	26%
								Standard Deviation of all Error (%)	43%	49%	28%	31%
								This accounts for positive and negative error values. Average Error (%) (+ & -)	30%	40%	5%	12%

	CUHP 1.4.4		Proposed CUHP	
	Large Basins	Small Basins	Large Basins	Small Basins
Percent of Time Computed Values are Greater than Recorded Values	61%	72%	42%	53%

Notes: HEC HMS Manual Chapter 9 references Error in Peak is Found with:

$$Z = 100\left|\frac{q_S(peak) - q_O(peak)}{q_O(peak)}\right|$$



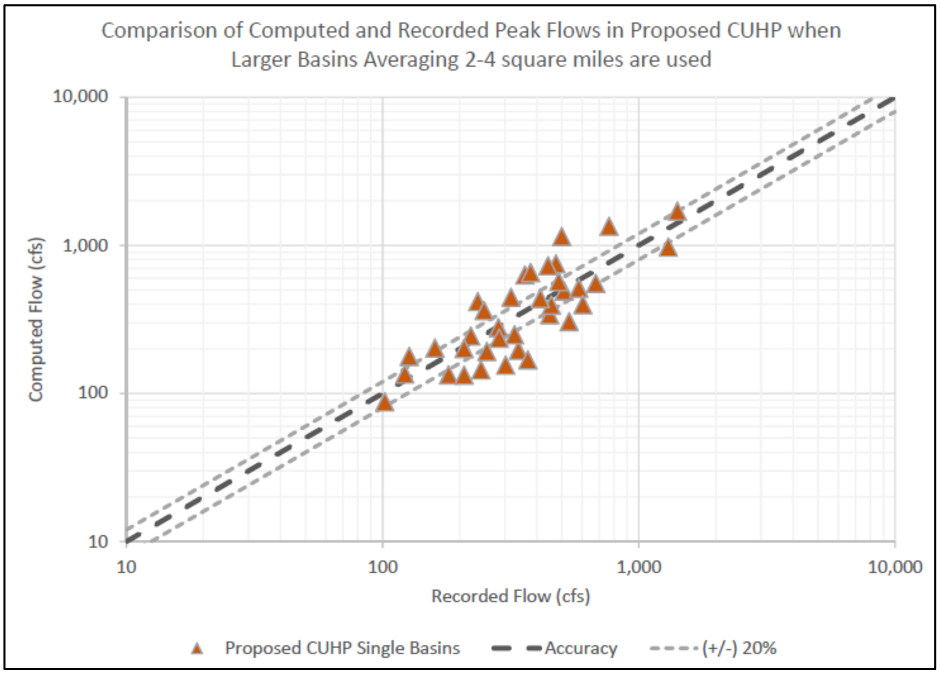
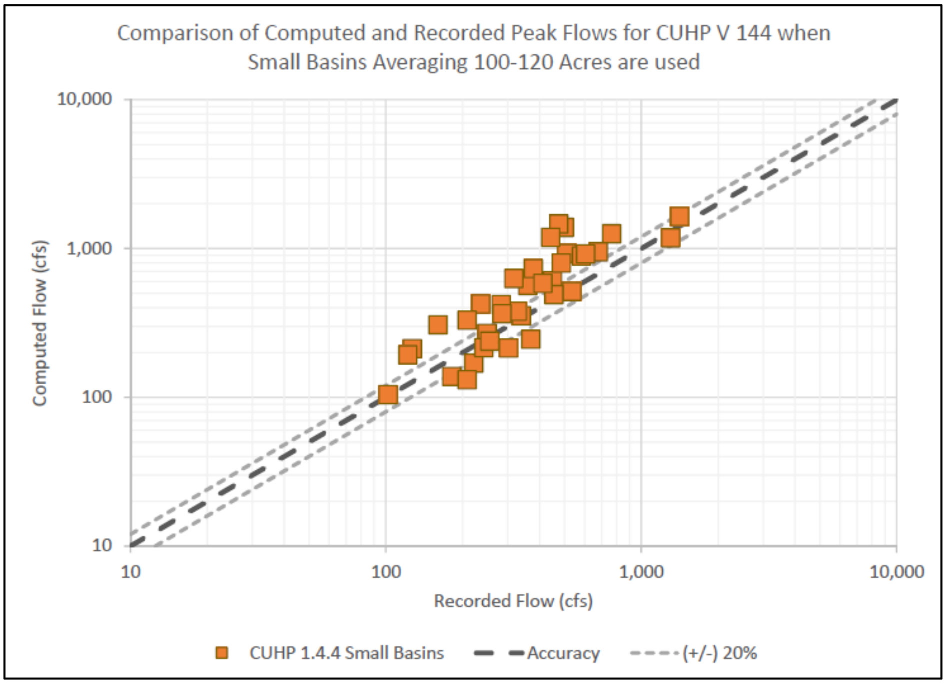


Figure 4 – Accuracy Plots of Proposed CUHP Calibration Testing for both smaller CUHP Basins Routed Via SWMM5's Kinematic Wave Method (Top) and larger CUHP Basins ranging from 2 to 4 square miles. (+/- 20%) Bands are included to represent potential gage error that is innate with stream gage networks.



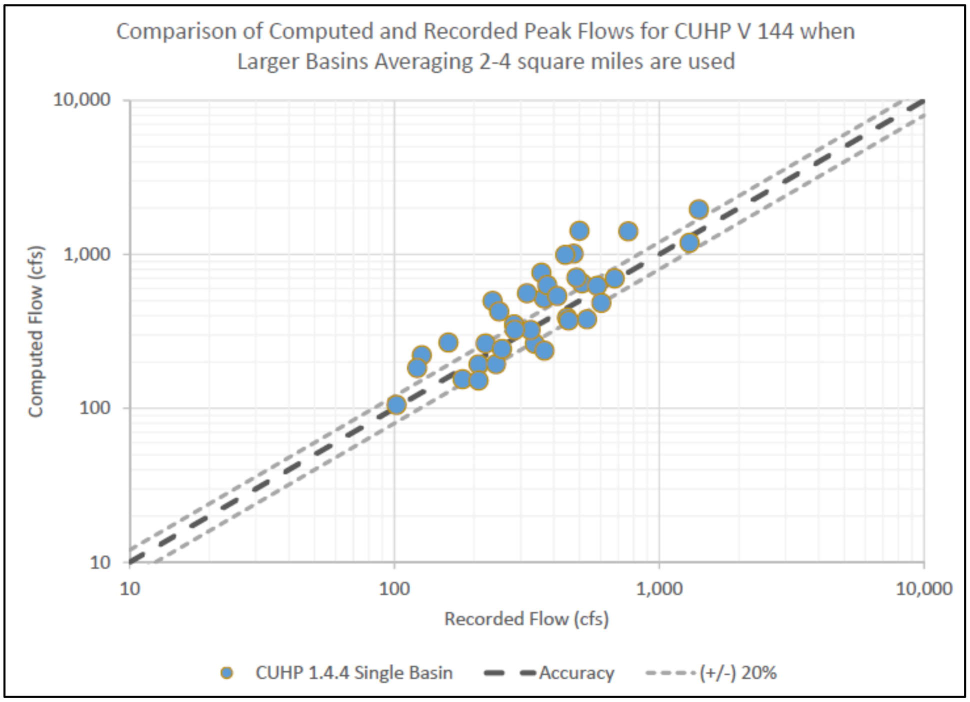


Figure 5 – Comparison of CUHP 1.4.4 with small basins (Top) and Large Basins (bottom). Note that almost all values sit at or above the line of accuracy.

COMPARISON OF DESIGN STORMS AND GAGE FREQUENCY

Goldsmith at Eastman

The below graph compares a Log Pearson III gage frequency analysis and the computed flow rates from CUHP 1.4.4 and Proposed CUHP.

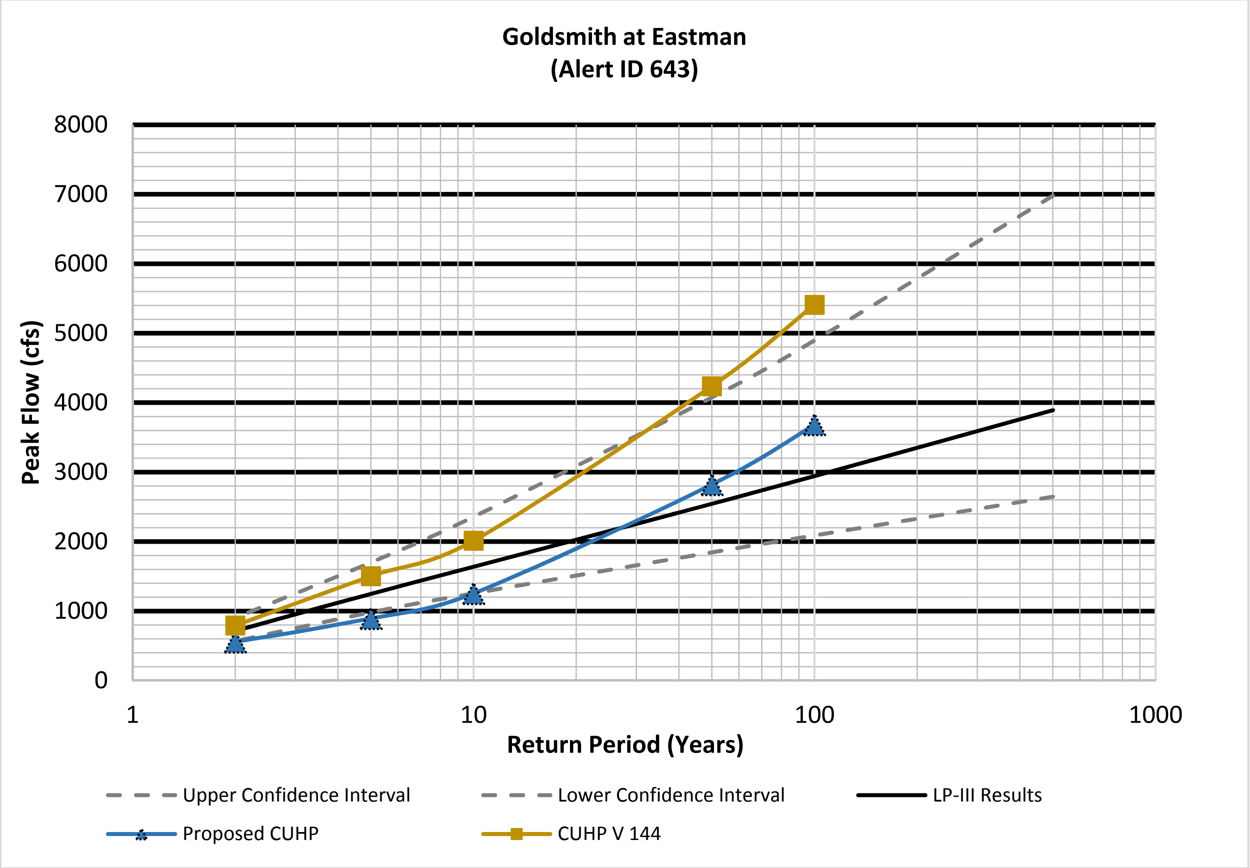


Figure 6 – Frequency Testing of Goldsmith Gulch Gage

Harvard Gulch

The 2015 Major Drainageway Planning (MDP) Model was used as a comparison for the small CUHP Basins and a larger, single basin model was developed for Upper Harvard Gulch. This study applied eight (8) GARR events in addition to the 2, 5, 10, 50, and 100-year storm frequency design events for testing. Multiple 2D hydraulic scenarios were performed using the most up to date LiDAR to determine the likelihood of the canal spilling during storm events. If the canal is running full during a storm, there is a possibility that some spilling occurs at a few locations in the upper Harvard gulch watershed.

Figure 7 - Image of 2D Rain on Grid Model of Upper Harvard Gulch at the Highline Canal

The below graph compares the values from the Proposed CUHP, CUHP Version 1.4.4, and the MDP CUHP model that included adjusted Cp values. All are compared with the Log Pearson III Statistical Gage Analysis for the USGS Stream Gage upstream of Jackson Street and also at Harvard Park.

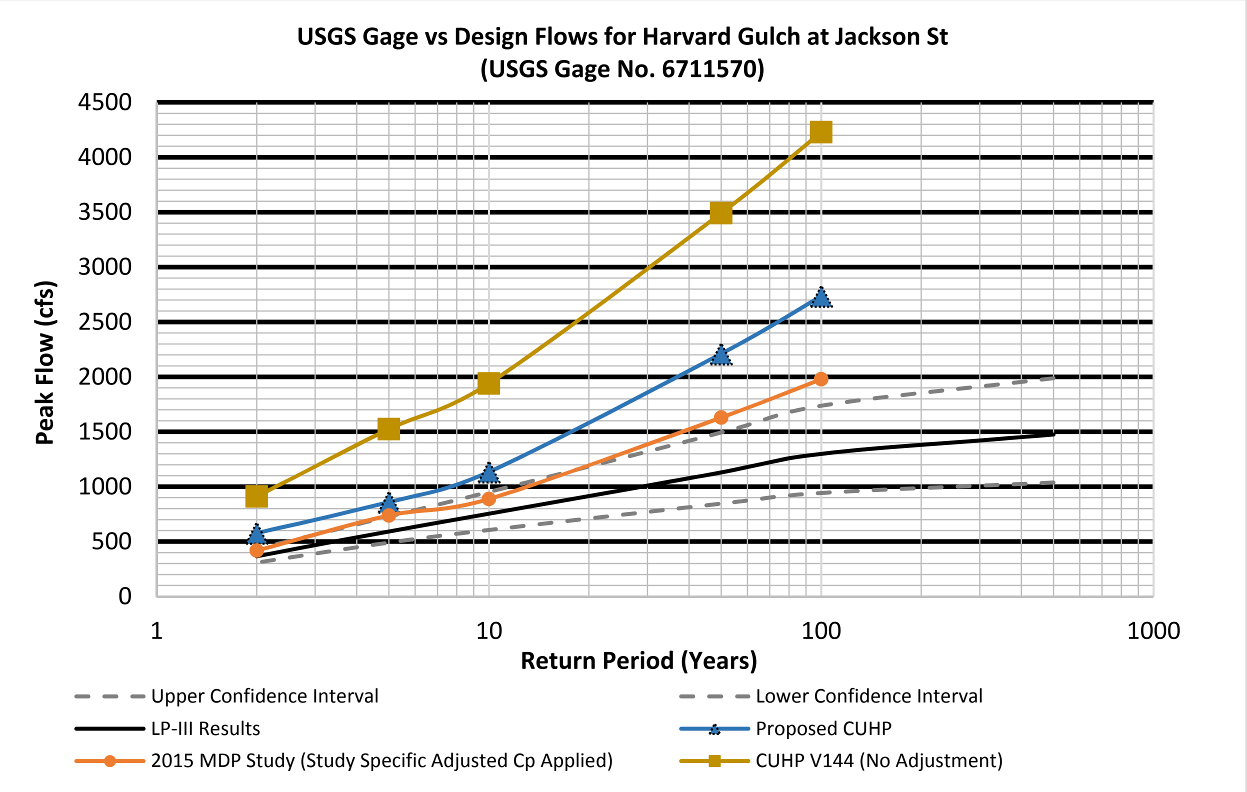


Figure 8 - Gage Frequency Comparison for Upper Harvard Gulch at Jackson St (Note 2015 MDP Has Study Specific Cp and Ct)

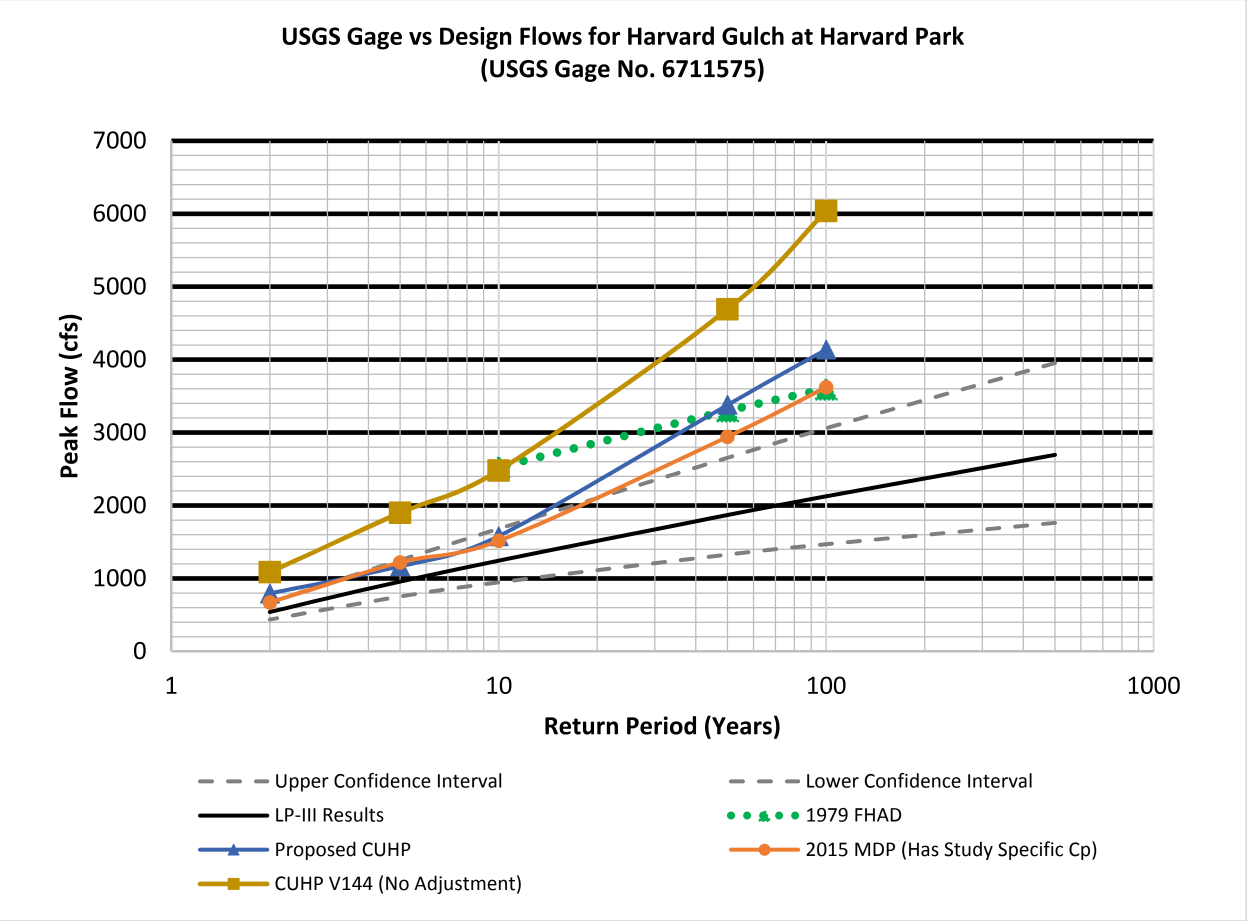


Figure 9 - Frequency Comparison for Harvard Gulch at Harvard Park

Willow Creek

The Willow Creek MDP adjusted the directly connected and receiving portions of CUHP's rainfall loss functions to adjust the reported peak flows. Additionally, the model modified Manning's n values to further refine the peak flows in the study. The resulting MDP flows fall within the bounds of a Log Pearson III statistical analysis. Presented below are the results from the 2008 MDP model, results from CUHP 1.4.4 without any calibration, and then the results of the Proposed CUHP version all compared to a Log Pearson III Statistical Distribution of the Willow Creek Stream Gage.

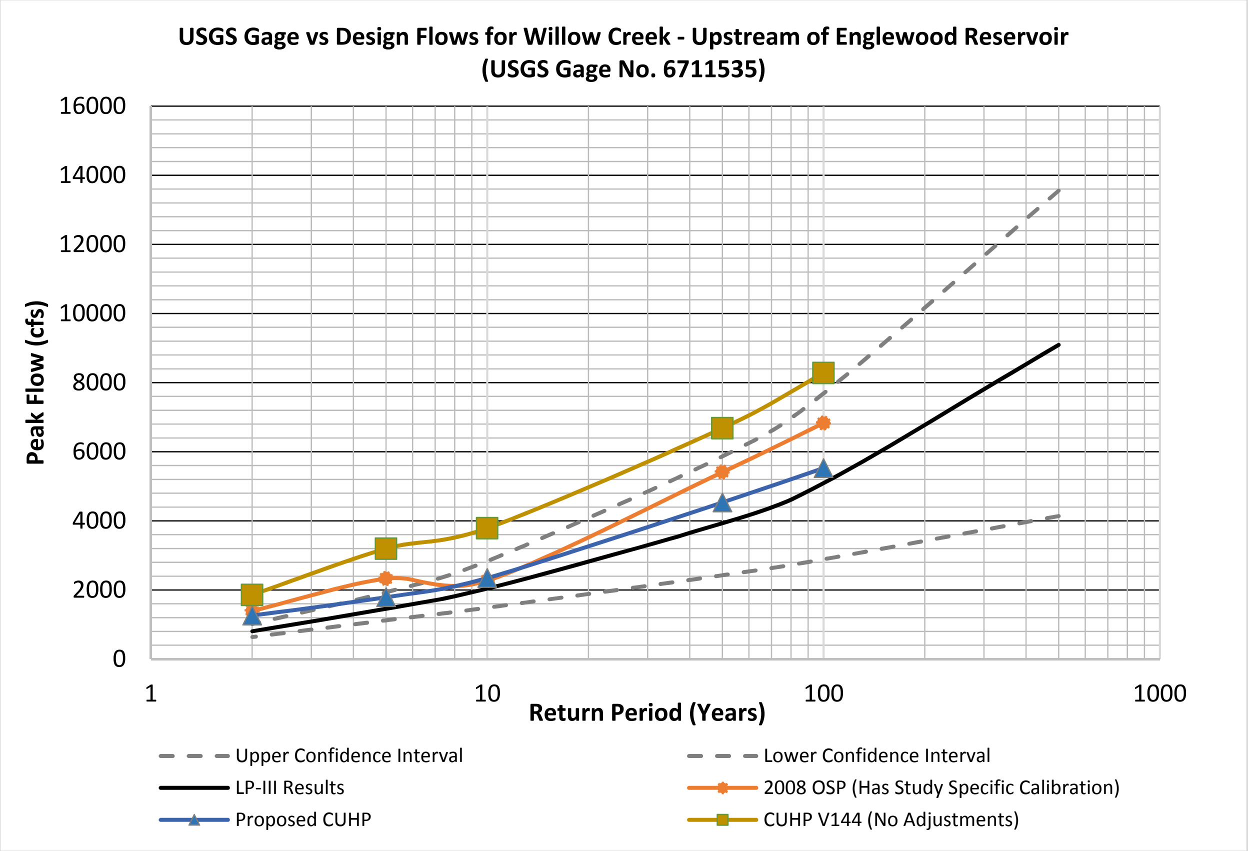


Figure 10 Frequency Testing for Willow Creek

Little Dry Creek near Arapahoe Rd

The gage at Little Dry Creek near Arapahoe Road was tested with many alternatives. This gage monitors flows from relatively dense development that consists of commercial and residential development. A hydrologic model was developed with sub-watersheds were to an average of 54 acres to test the performance of CUHP with small, developed basins. A 2D Diffusive wave and SWMM5 Overland Flow Kinematic Wave model was also developed, however, those results are not relevant for this report and are not discussed further. Figure 1 below is caption of the watershed above Little Dry Creek near Arapahoe Rd.

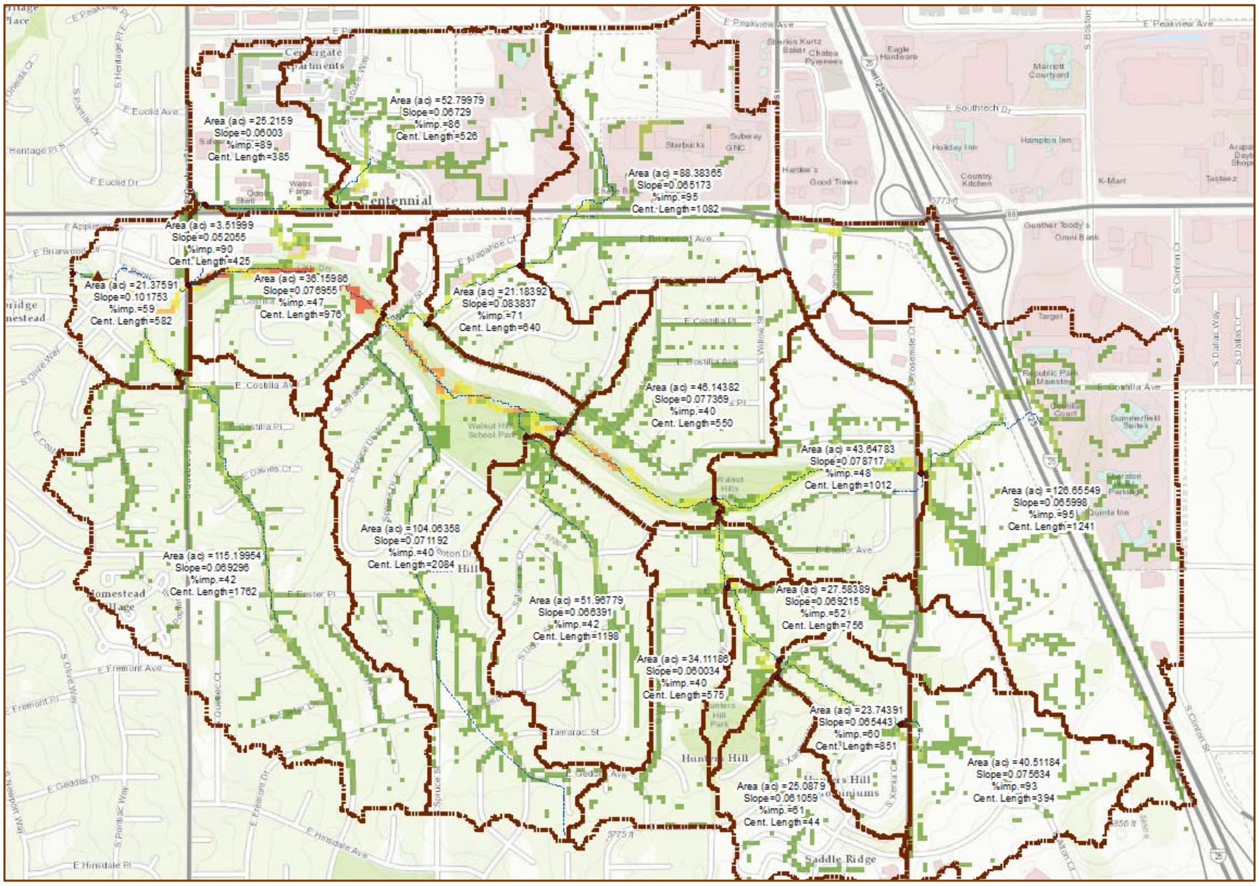


Figure 11 - Image of LDC Arapahoe Basins and 2D Flow Grid

The flow history of this gage goes back to 1985, and serves as a good gage for frequency testing since it is relatively un-influenced by major detention facilities, has a decent length of record, and is not influenced by backwater at the gage location. As shown in the figure below, the Proposed Version of CUHP still sits above the gage frequency curve and provides a conservative estimate of design flows at this gage.

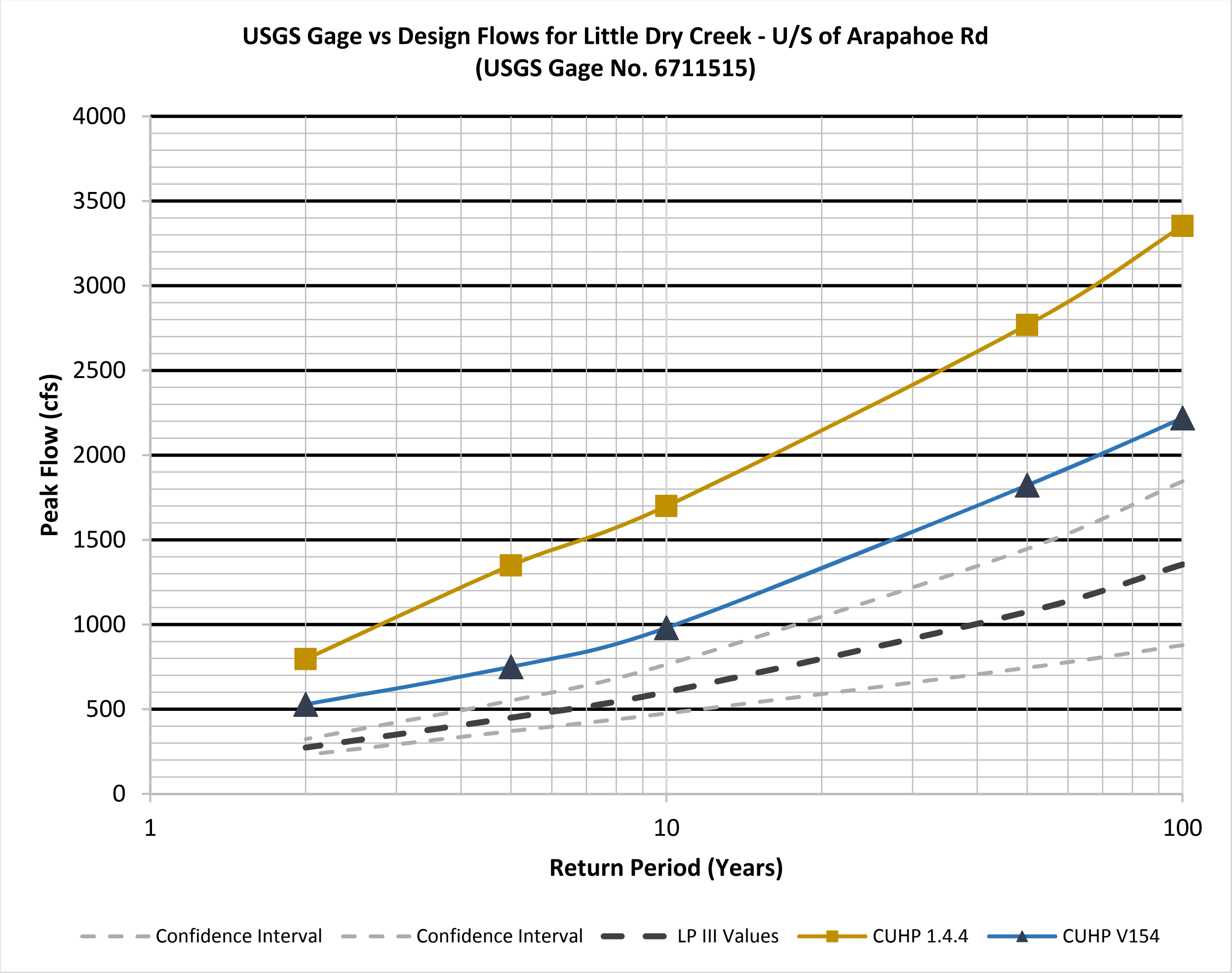


Figure 12 - Gage Frequency for Little Dry u/s of Holly Reservoir near Arapahoe Rd

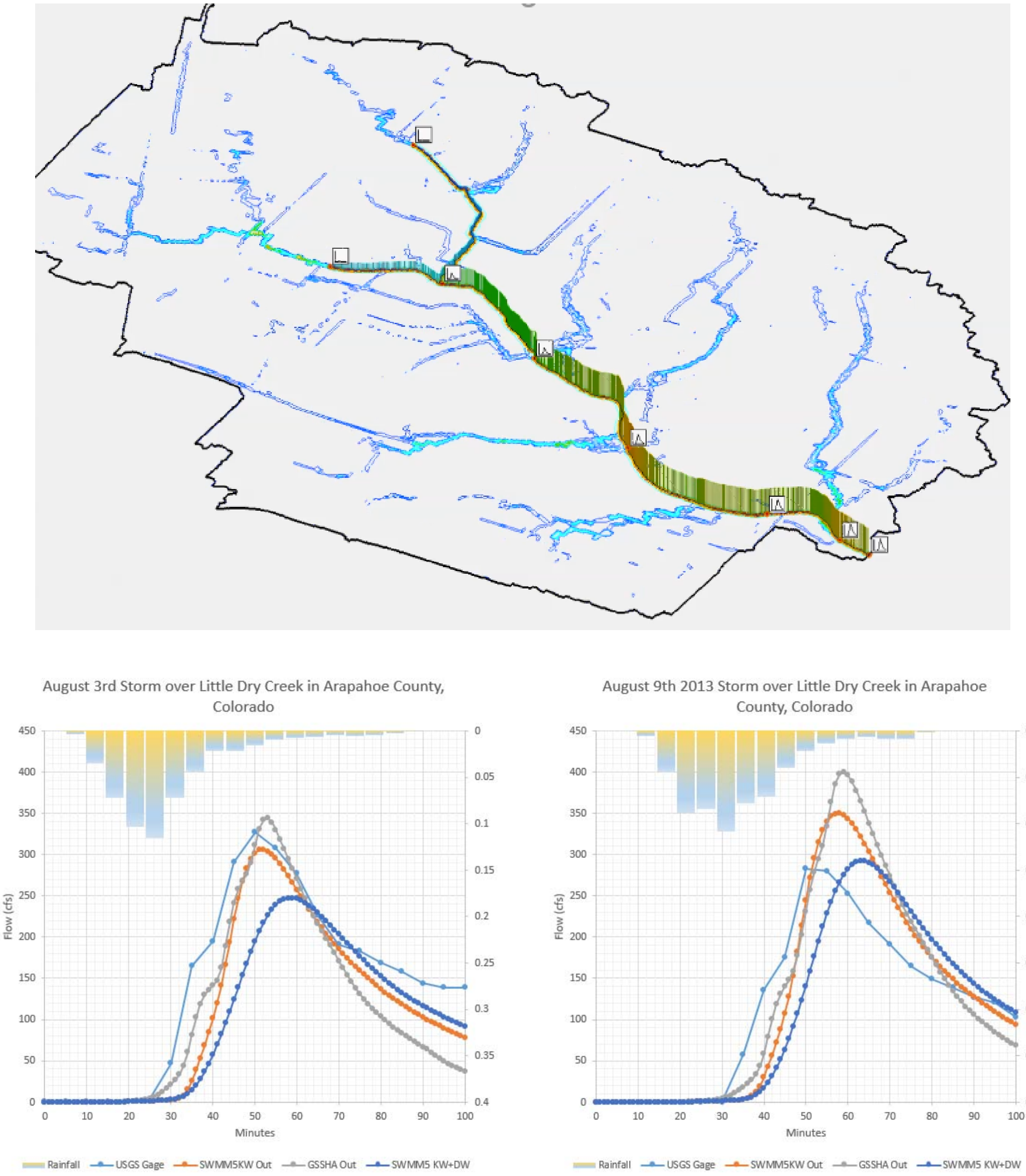


Figure 13 - Image of 2D Diffusive Wave, Kinematic Wave, and Dynamic Wave Testing on LDC near Arapahoe Rd

Dutch Creek at Platte Canyon Rd

Dutch Creek was compared due to the large difference between the existing major drainageway plan and the gage frequency curve. After analyzing the effects of routing in this basin, it was noted that there are a few locations that contain storage facilities that aren't qualified to be included in the regional hydrologic model since they're not formal detention. The image below highlights the Dutch Creek Watershed and the orange circles present the numerous formal and informal detention facilities that have a large effect on the gage's frequency analysis.

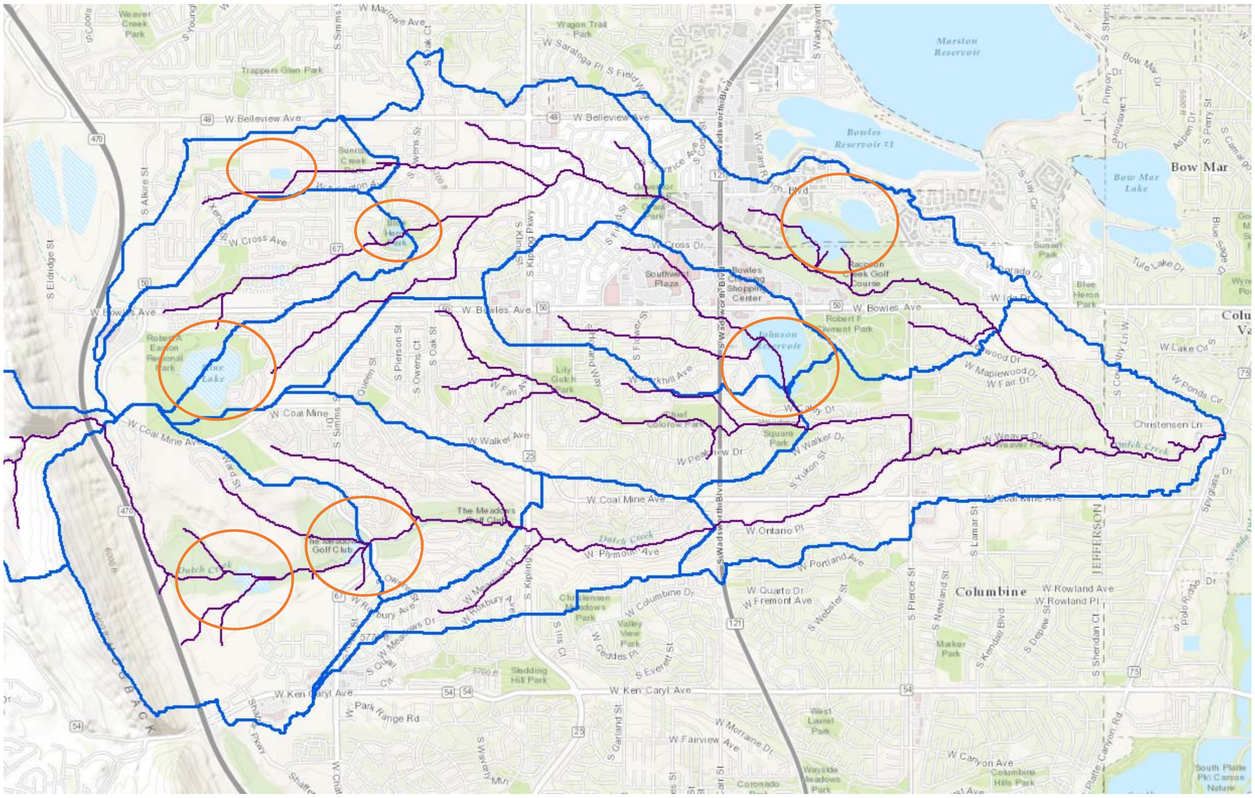


Figure 14 - Dutch Creek Watershed and Numerous Detention Locations

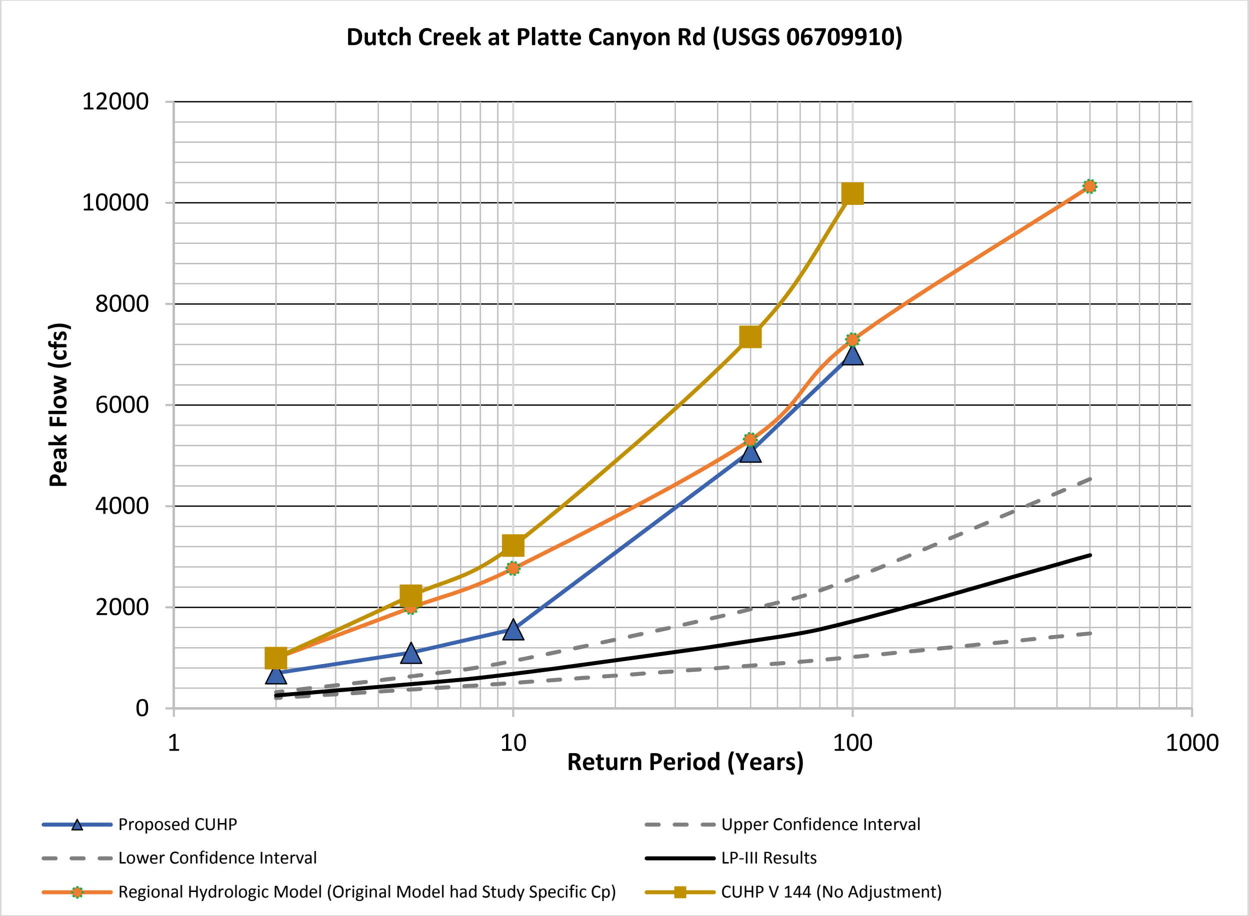


Figure 15 - Dutch Creek Frequency Curve

North Sanderson Gulch in Lakewood (Upstream of Wadsworth)

North Sanderson Gulch in Lakewood was originally selected for rainfall and runoff calibration but the gage record is not recent enough to compare with GARR rainfall. However, the basin is a good basin for frequency comparison because it is relatively small, has limited detention, and is mostly developed with residential neighborhoods and planned open spaces.

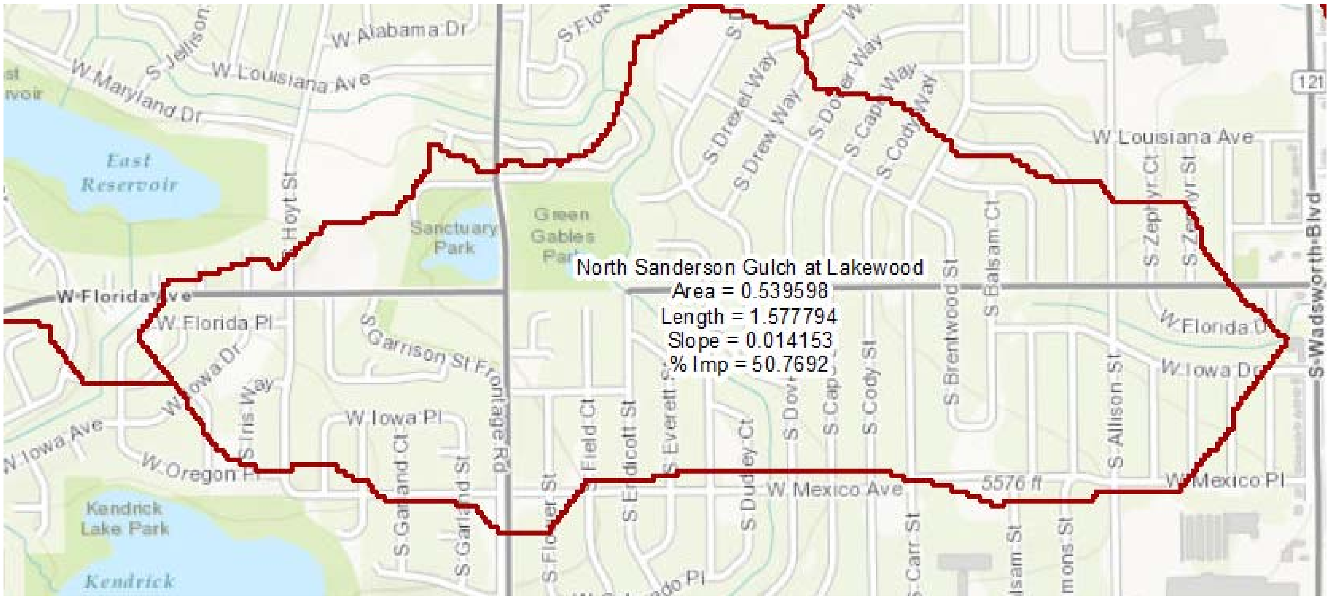


Figure 16 - Sanderson Gulch at Lakewood Upstream of Wadsworth

As presented below, the Proposed Version of CUHP sits near the upper confidence interval of the frequency analysis.

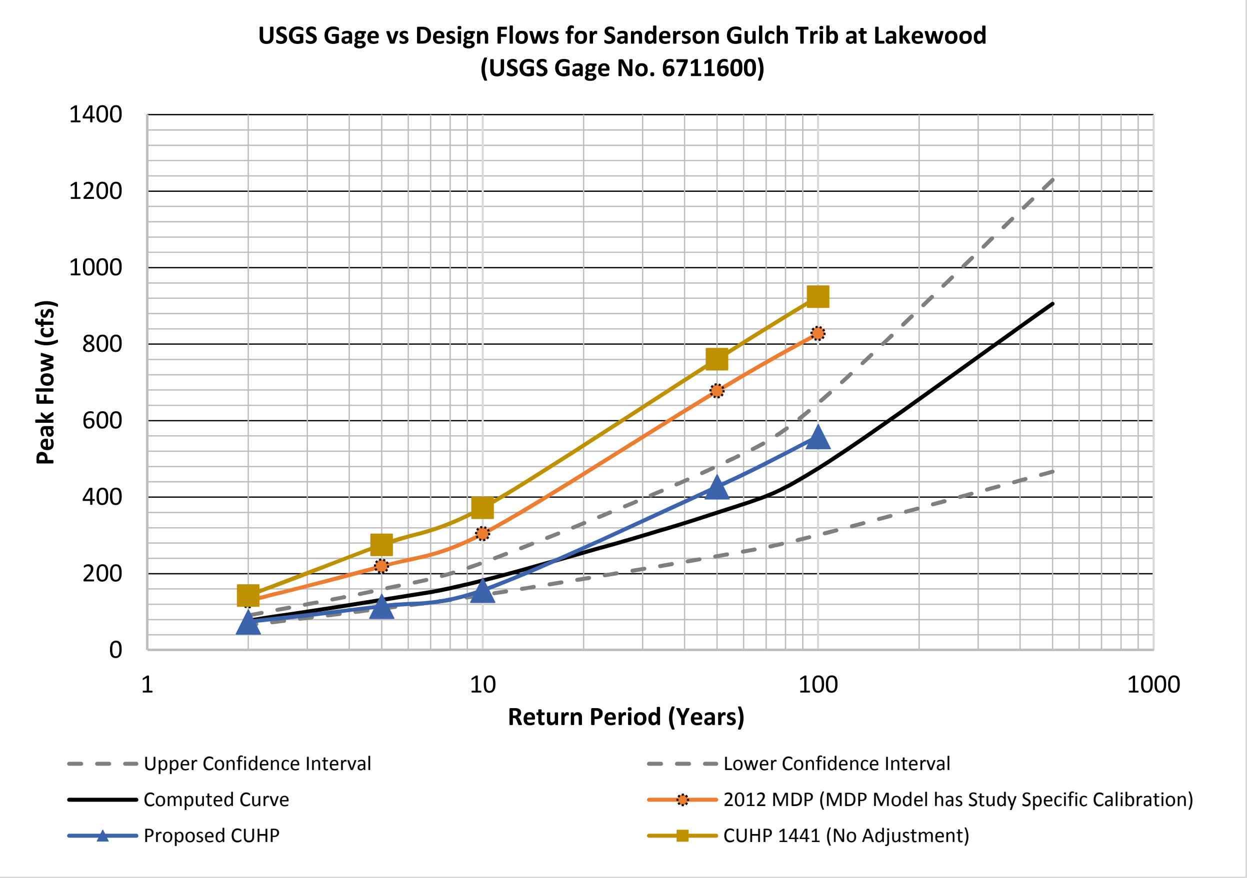


Figure 17 - Frequency Curve for North Sanderson Gulch above Wadsworth

Dry Gulch at Denver

Dry Gulch in Denver begins in Lakewood Colorado upstream of Colfax and Simms St and progresses through a series of urban, mostly residential drainages until the USGS gage at Perry Street just north of 10th Avenue in Denver, CO. The 1995 OSP Phase B had a design discharge of 2,200 cfs for the 100 year flow. There is an ongoing master plan update during the time of this study and the values in the graph below may vary from that update depending on modeling details.

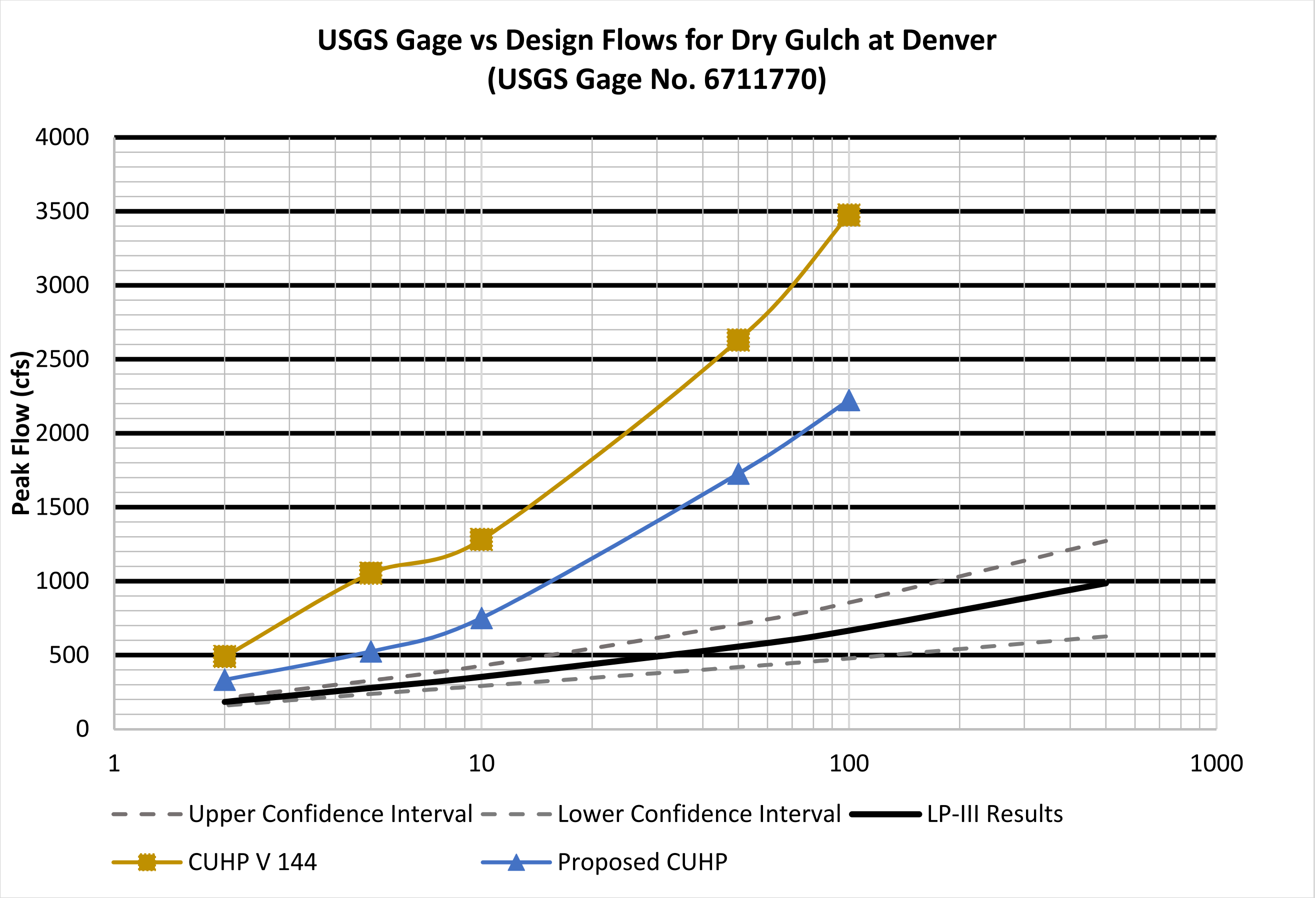


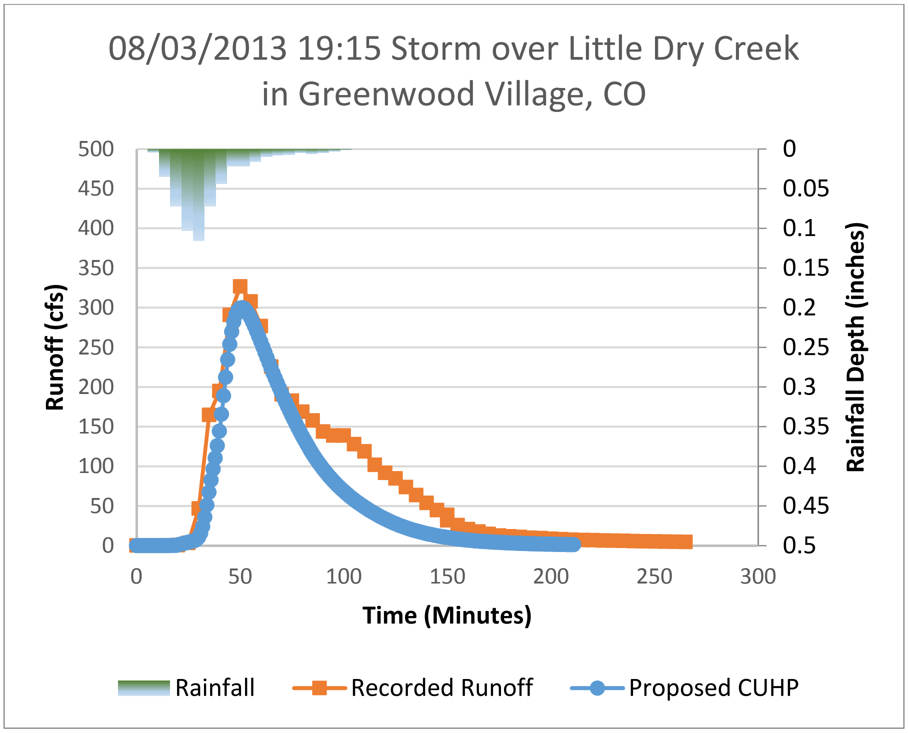
Figure 18 – Frequency Curve for Dry Gulch in Denver, CO at Perry St. North of 10th Ave.

HYDROGRAPH TIMING

This re-calibration effort made modifications to the timing coefficients for small sub-catchments and subsequently required testing of the hydrograph timing between rainfall and recorded flows at the stream gage. Table 3 and the Figures below present the hydrograph timing from the beginning of a recorded storm event to the peak of the flow hydrograph and the time to peak from the beginning of the hydrograph to the hydrograph peak.

Table 3 - Comparison of Hydrograph Timing at Little Dry Creek USGS Gage

Storm ID	Beginning of Storm	Total Depth	Proposed Version of CUHP		USGS Gage at Little Dry Creek above Arapahoe Rd	
			Time to Peak from beginning of Hydrograph (Minutes)	Time to Peak from Beginning of Storm (Minutes)	Time to Peak from beginning of Hydrograph (Minutes)	Time to Peak from Beginning of Storm (Minutes)
Storm 1	2013-08-03 19:15	0.551	36	51	35	50
Storm 2	2013-08-09 15:25	0.591	32	52	25	50
Storm 3	2014-07-14 21:30	0.835	27	82	30	80
Storm 4	2014-08-07 12:30	0.416	27	42	30	35
Storm 5	2014-09-29 14:10	0.349	24	50	25	40
Storm 6	2015-06-11 17:25	1.388	41	86	50	90
Storm 7	2015-07-18 16:10	0.326	32	62	35	65
Storm 8	2015-08-10 13:20	0.903	38	88	40	85
Storm 9	2016-08-03 18:20	0.405	24	99	25	95



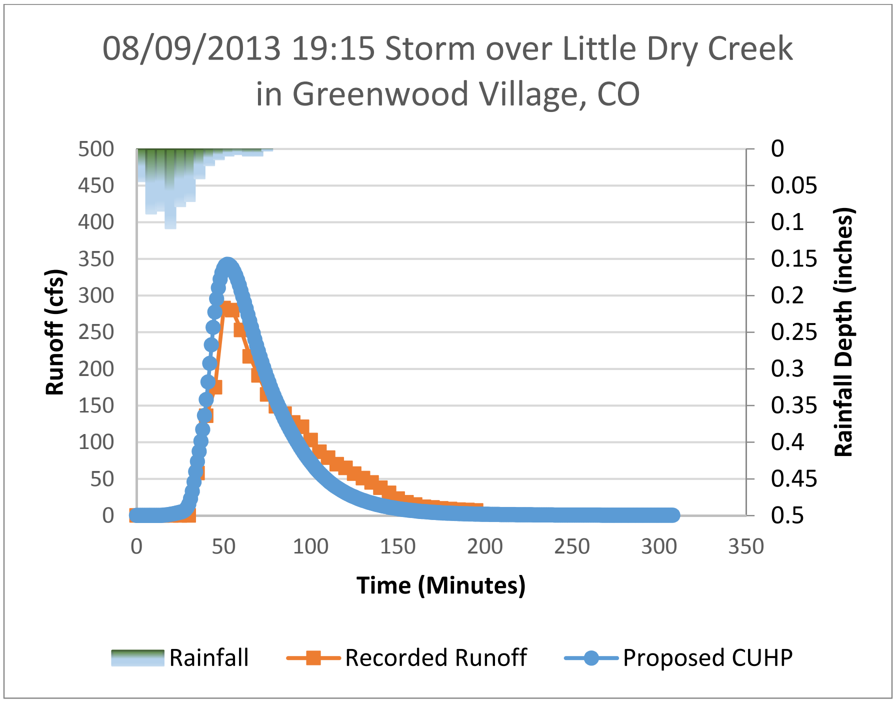
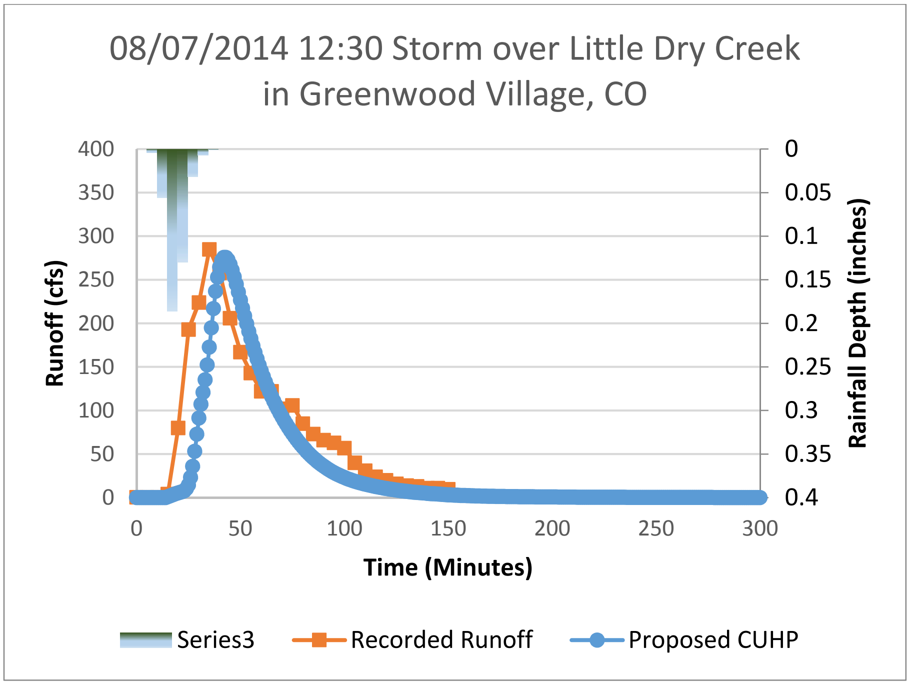


Figure 19 – Recorded and Predicted Hydrographs showing Hydrograph Timing



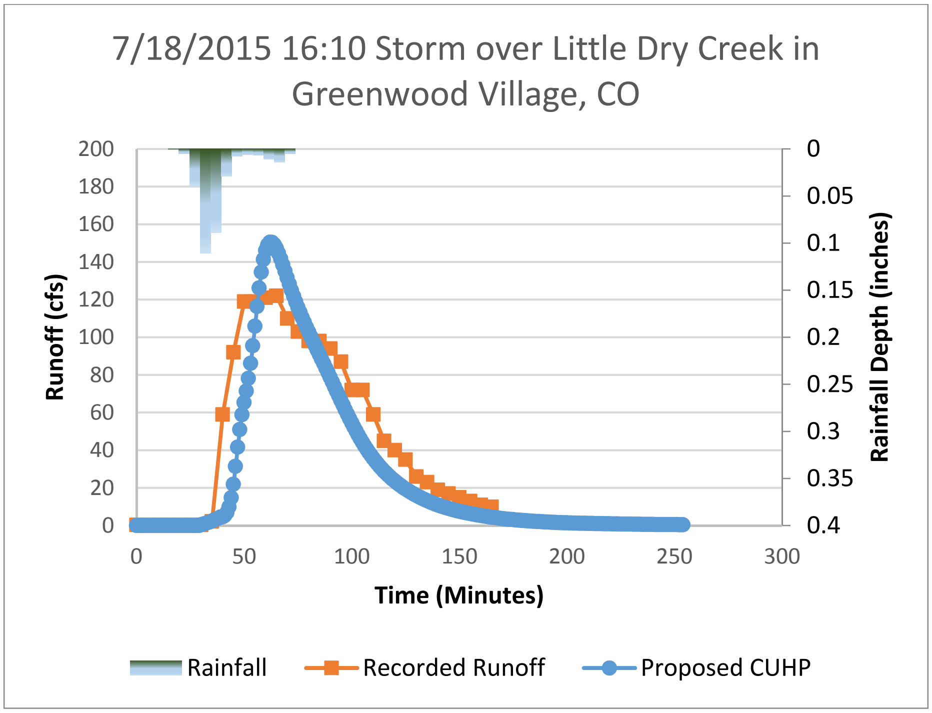
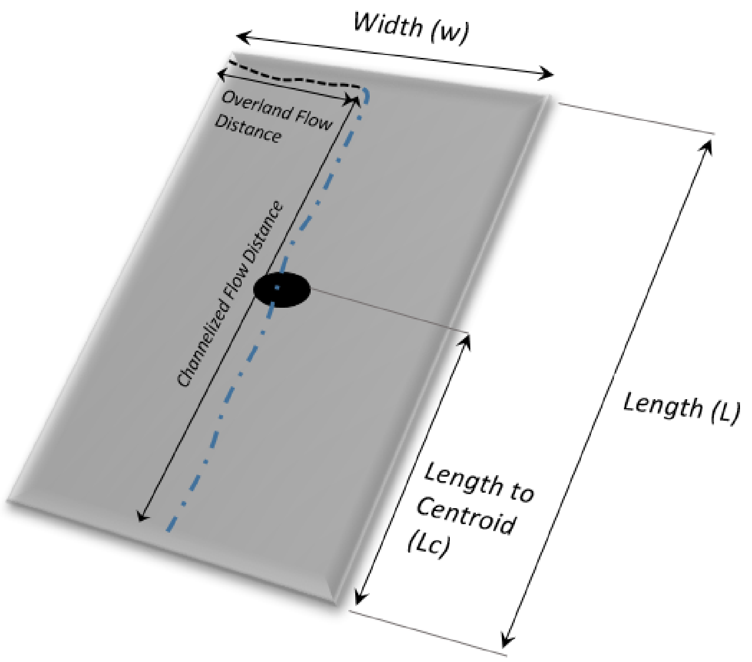


Figure 20 - Recorded and Predicted Hydrographs showing Hydrograph Timing

TESTING BETWEEN THE PROPOSED CUHP AND RATIONAL METHOD

Modifications to CUHP within this summary report adjusted how CUHP computes the peak flows for urban drainage basins. A comparison between the commonly applied Rational Method was tested to ensure that the peaking within the proposed changes did not dramatically alter the expected flows between the Rational Method described within the District's Criteria Manual and the proposed version of CUHP. Preliminary testing between the two methods considered a hypothetical basin that is twice as long as it is wide. Overland and channel flow times were developed based on equations within the UDFCD Manual. The figure below is a layout of the hypothetical basin used for this comparison.



$$A = w * L, and\ L = 2w$$

$$w = \sqrt{A/2}$$

$$L = 2 * \sqrt{A/2}$$

Water Way Length for Channelized Flow:

$$L_t = 2 * \sqrt{\frac{A}{2}} = 2 * w$$

Water Way Length for Channelized Flow when 1/2w is greater than 350':

$$L_t = 2 * \sqrt{\frac{A}{2}} = 2 * w + (L_0 - 350')$$

Length for Overland Flow:

$$L_O = \frac{1}{2} * w$$

Overland Flow not to be greater than 350'

Figure 21 – Characteristic Watershed for Rational Method Testing

The time of concentration for the rational method was developed by computing overland flow and channel flow times as presented in the Equations below:

Time of concentration (t_C) is found with,

$$t_c = t_i + t_t \tag{6}$$

Where (t_i) is the overland flow time computed by,

$$t_i = \frac{0.395(1.1 - C_5)\sqrt{L}}{S_o^{\ 0.33}} \tag{7}$$

Where C_5 is the 5 year runoff coefficient, S_0 is the flow slope, and L is the overland flow length not to exceed 350 feet (Guo 2006). Travel time in the main flow path was computed by,

$$t_t = \frac{L_t}{60K\sqrt{S_o}} = \frac{L_t}{60V_t} \tag{8}$$

Where, K is the conveyance coefficient, V is the approximate flow velocity, and S_0 is the channel slope. In the figure below, peak flow rates between the Proposed CUHP and the District's Rational Method are compared. As shown, the Rational Method trends a bit higher than the Proposed CUHP, however, the differences are not large. Further testing between the two methods may be warranted. Additionally, adjustments to the Rational Method that were made to match previous versions of CUHP may need to be revisited.

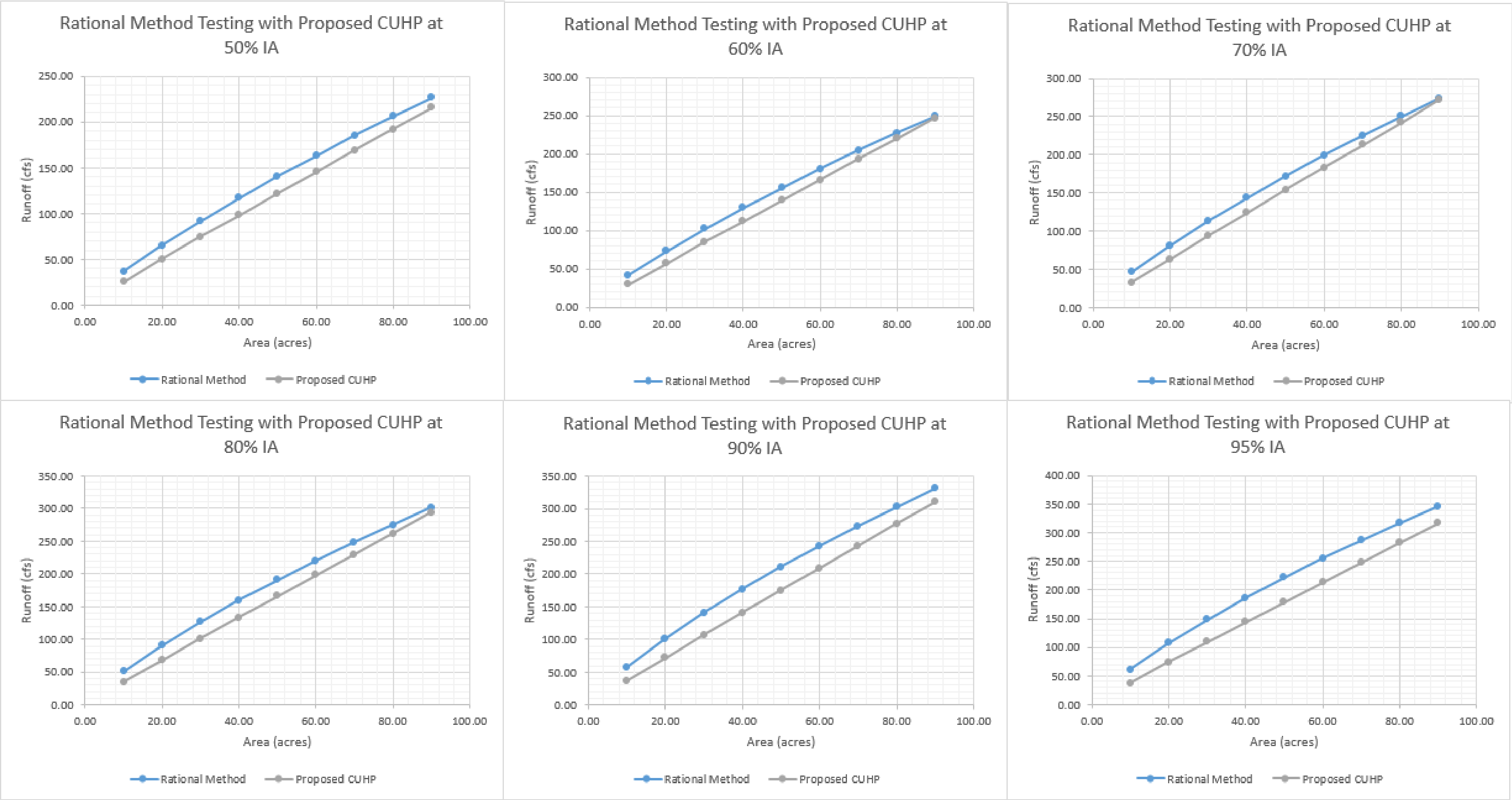


Figure 22 – Comparison of the Rational Method as Described in UDFCD's Criteria Manual with the Proposed CUHP for Imperviousness Values between 50% and 95%

RECOMMENDATIONS AND CONCLUSIONS

Changes to CUHP proposed within this report will lower peak flow rates for almost all studies across the District. However, as shown through comparison of gage frequency analysis, values produced with the proposed version of CUHP will still be conservative in most cases when compared to gage frequency estimates. Work performed though calibration found that CUHP Version 1.4.4 is statistically within range of recorded rainfall and runoff. However, Version 1.4.4 more often produced results higher than the recorded flow when compared to the proposed version of CUHP. Additionally, the proposed version of CUHP will trend more closely with gage frequency estimates than Version 1.4.4. In order to match both recorded rainfall and runoff values and gage frequency estimates, the most recently published 1 hour precipitation depths found in NOAA's Atlas 14 Precipitation Frequency Estimates are recommended. Adopting the most recently published rainfall depths to trend CUHP more in line with gage frequency estimates was recommended over adjustments to the temporal distribution of the UDFCD design storm.

In summary, recommendations from this project are for the District to adopt the following changes:

- Modify the equations within CUHP to be more in line with the recorded rainfall and runoff record analyzed through this study. Additionally, these modifications place design frequency closer to gage frequency analysis for clean, developed basins with a good gage record.
- Adopt NOAA's rainfall atlas Volume 14 for point precipitation depths within the District. Without this adoption, CUHP will remain higher when compared to frequency analysis at trusted gages.

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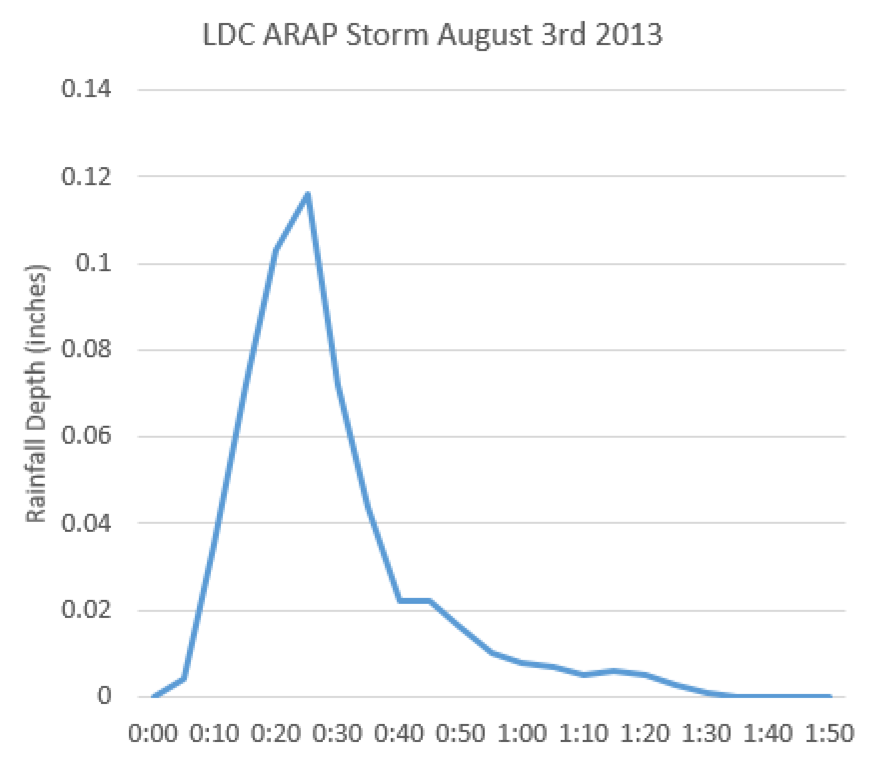
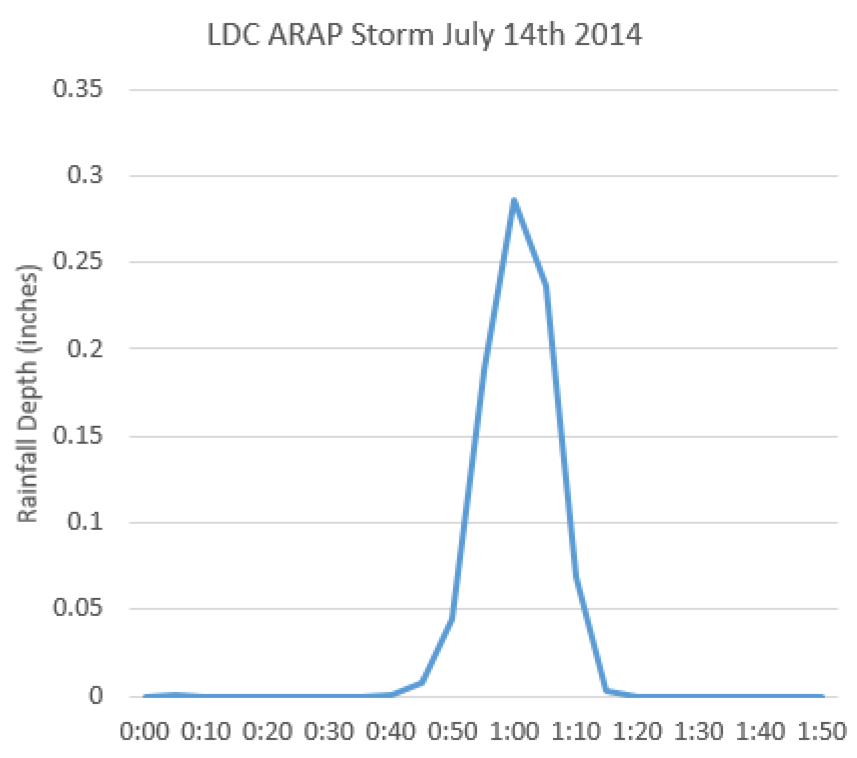
Appendix A – GARR Rainfall Hyetographs

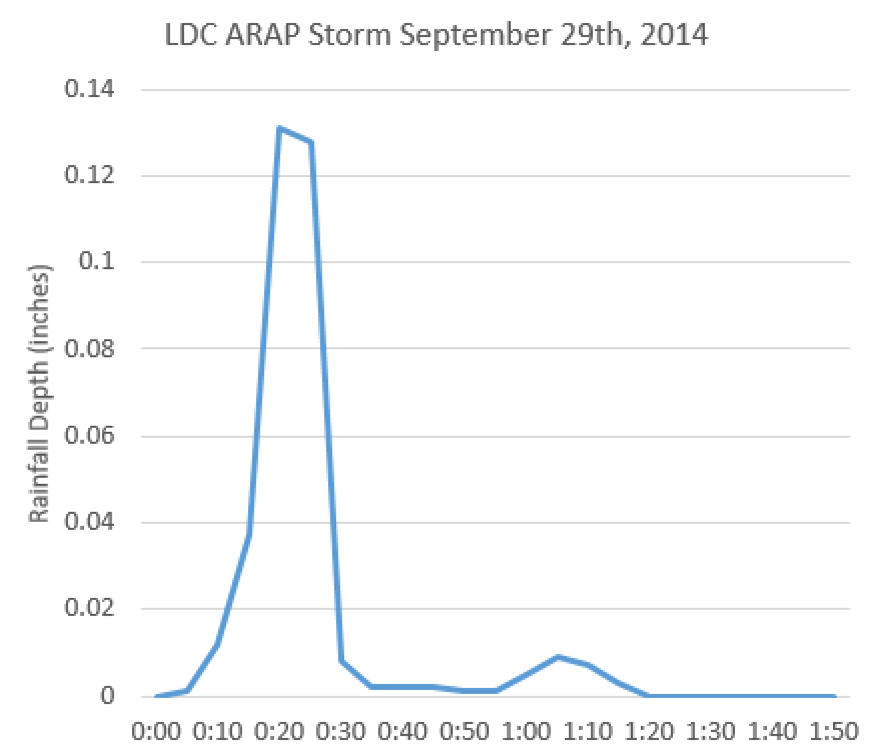
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis



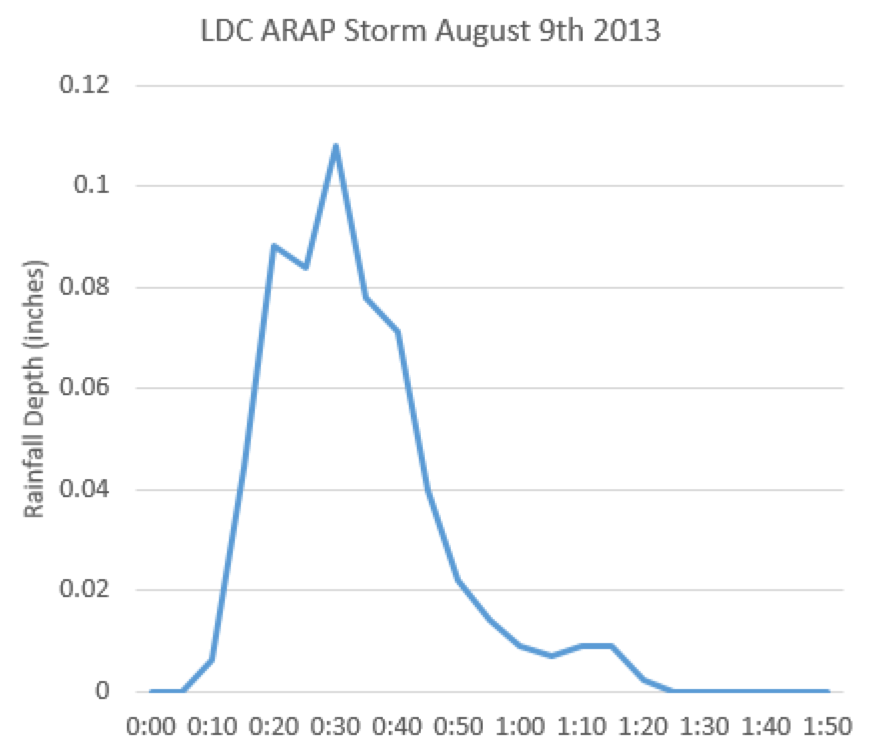
LDC ARAP Storm August 3rd 2013



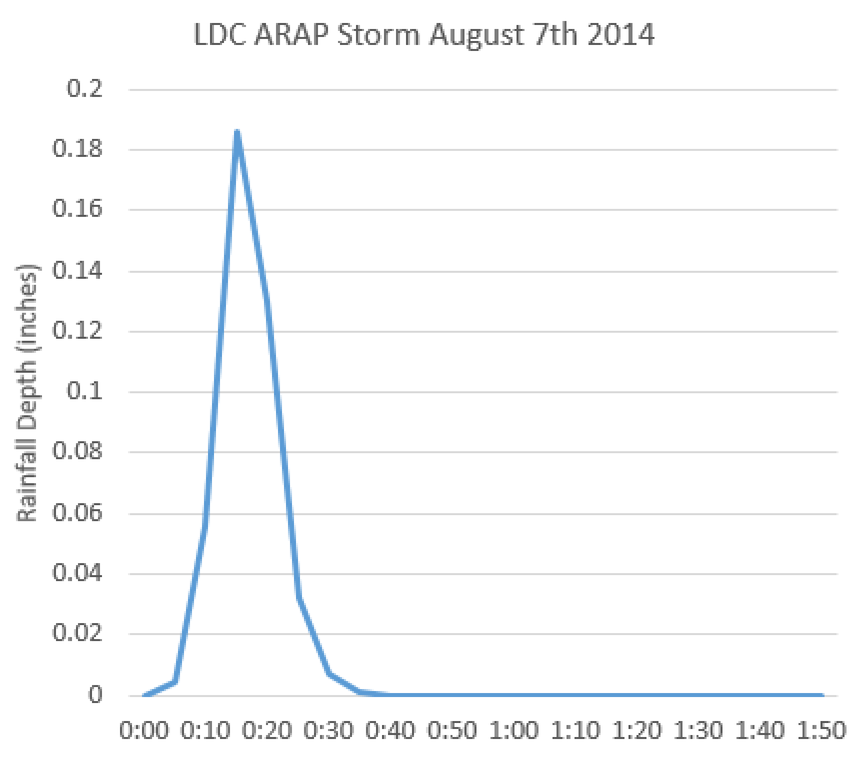
LDC ARAP Storm July 14th 2014



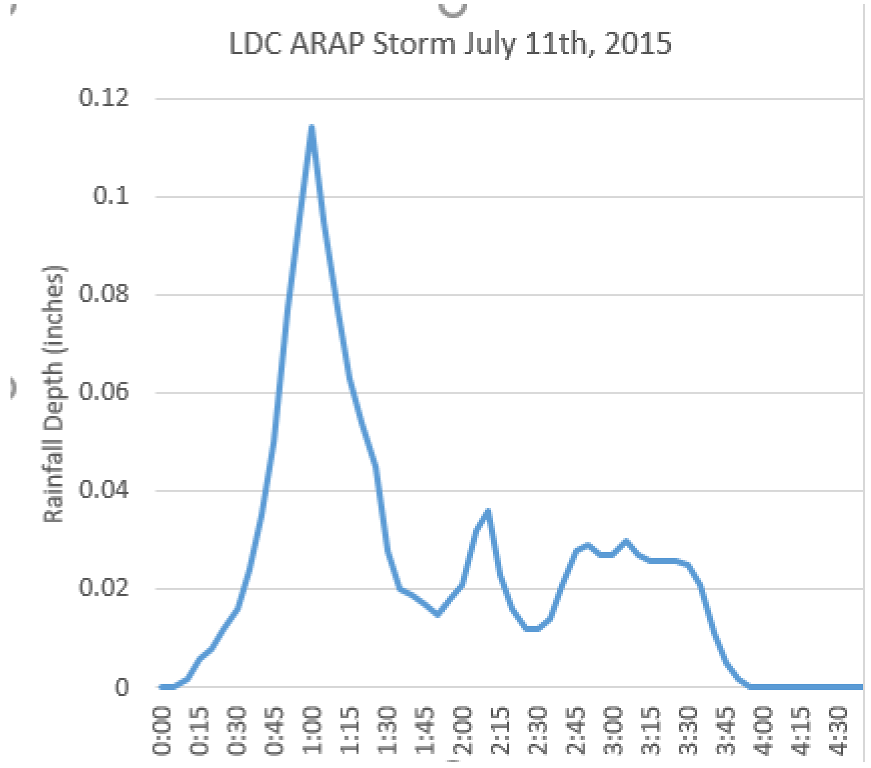
LDC ARAP Storm September 29th, 2014



LDC ARAP Storm August 9th 2013

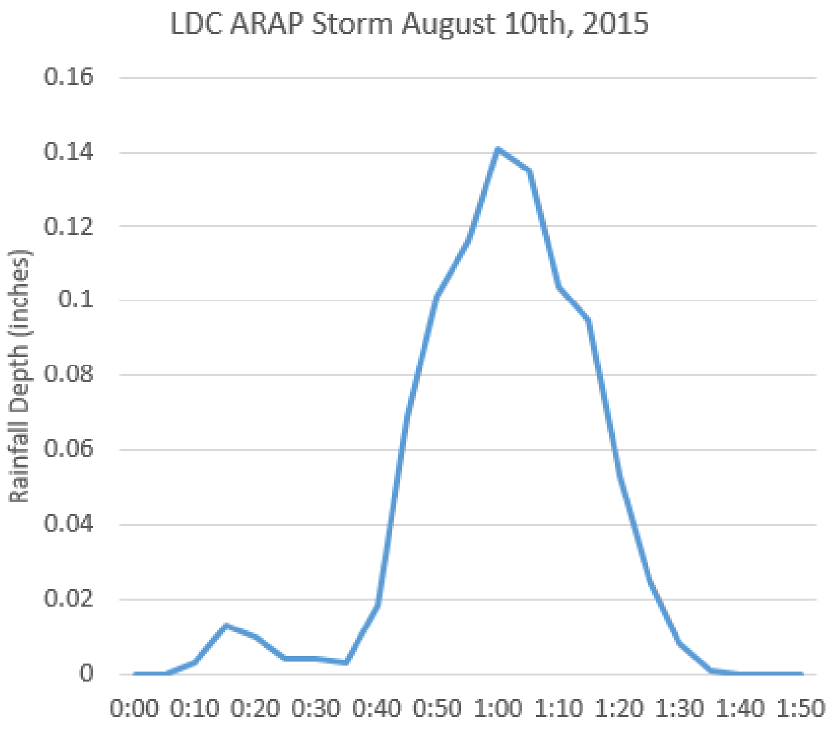


LDC ARAP Storm August 7th 2014



LDC ARAP Storm July 11th, 2015

This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis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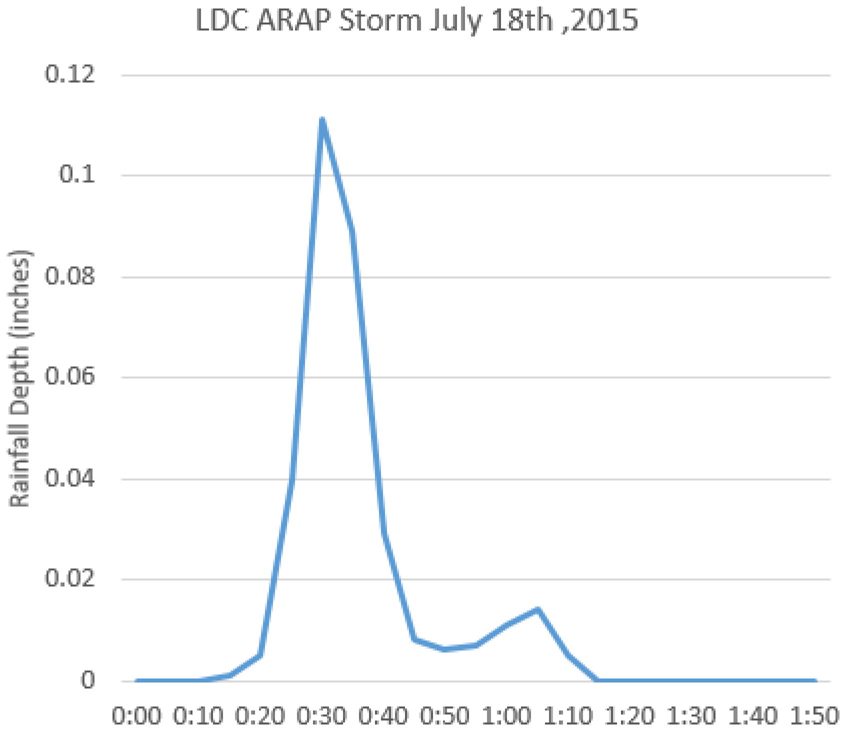
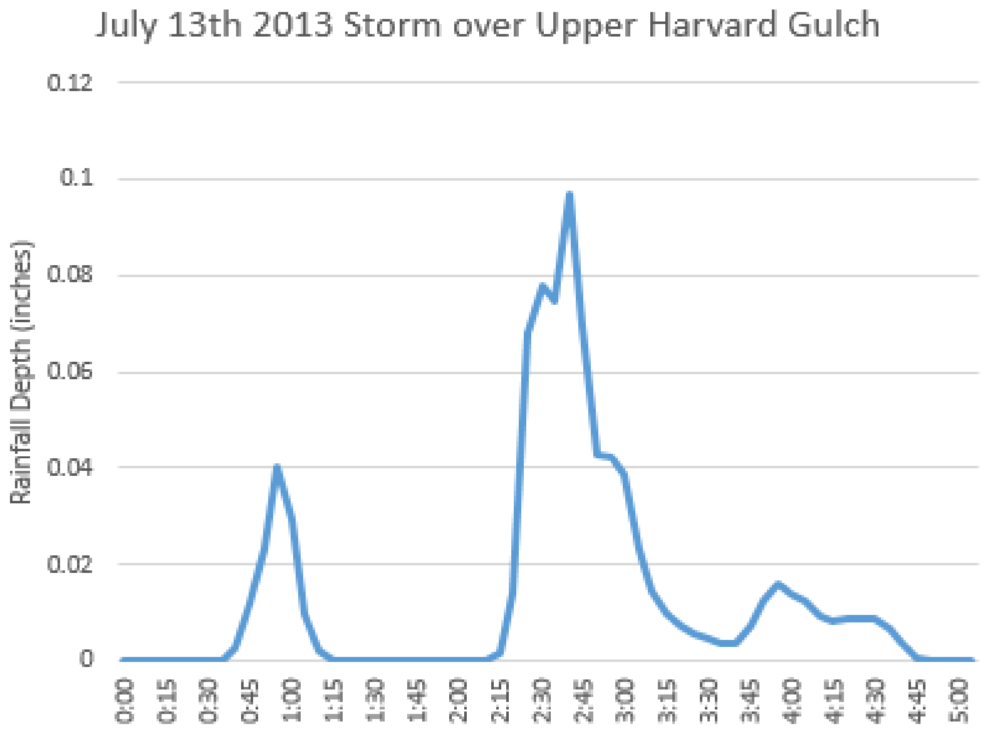
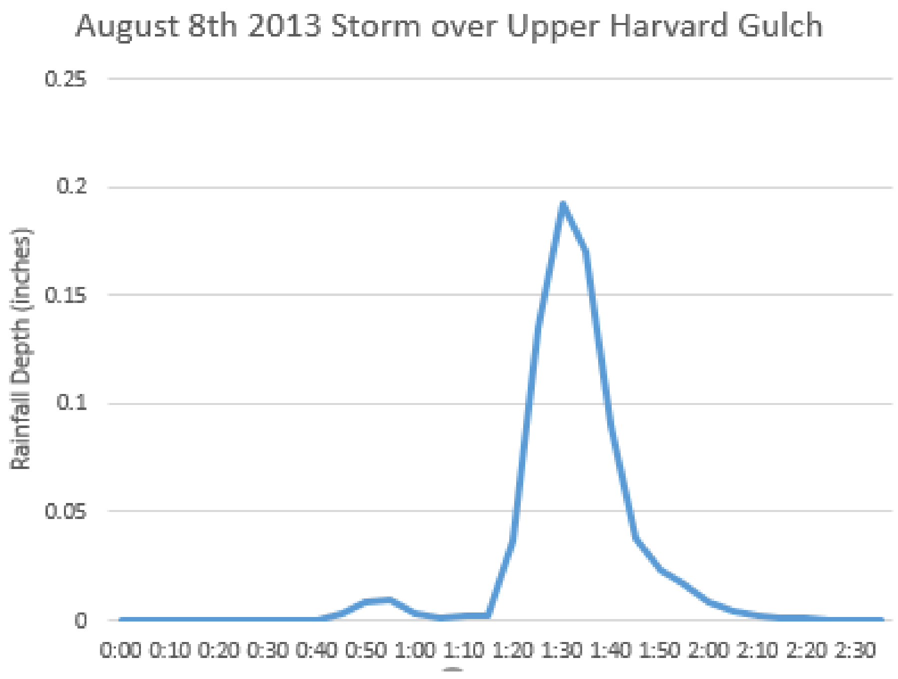
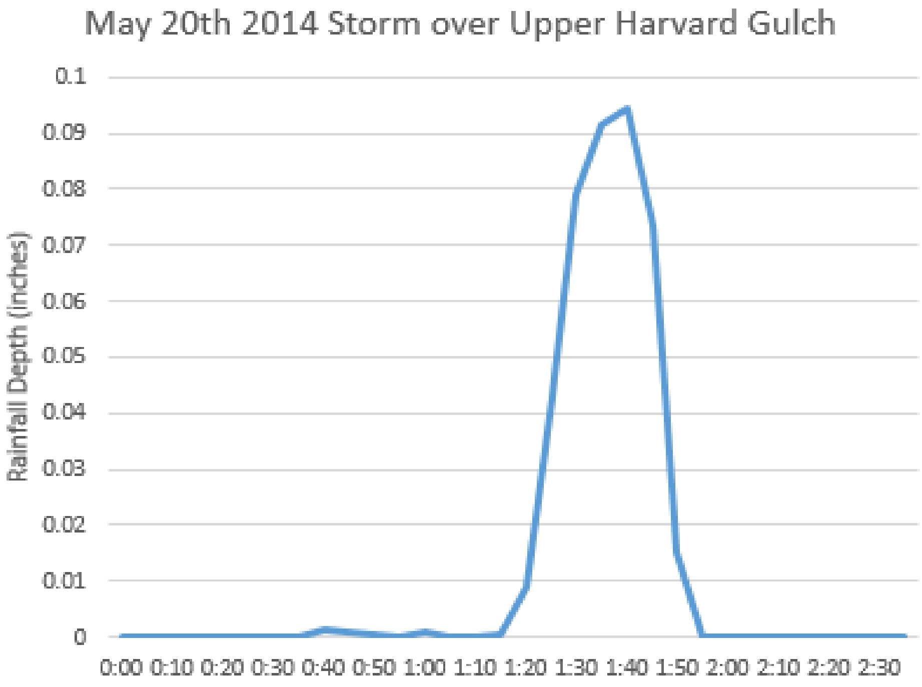
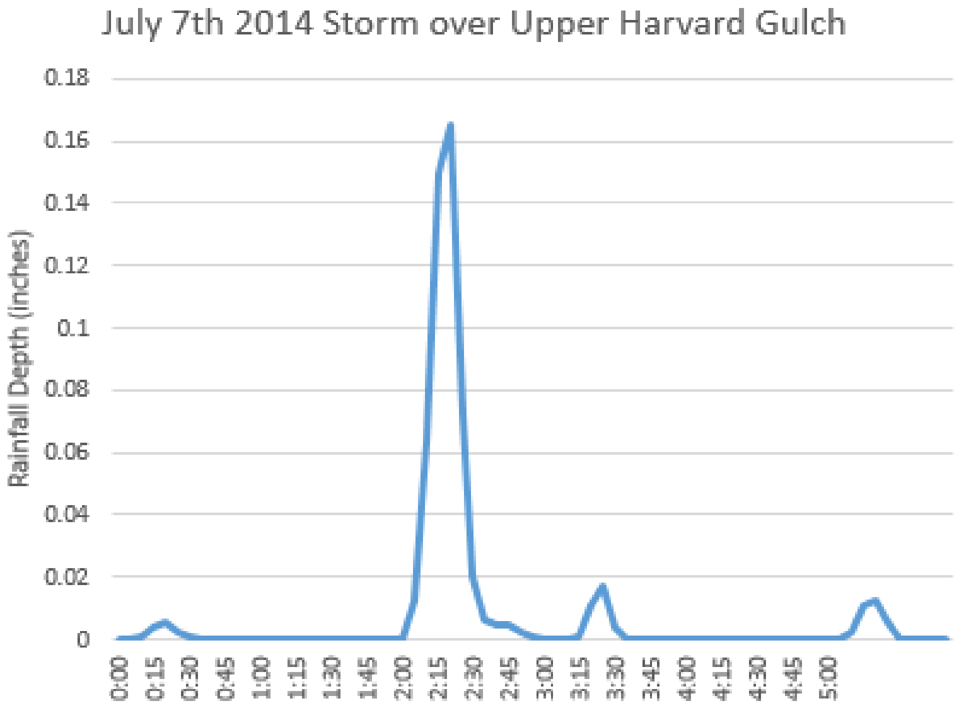

LDC ARAP Storm July 18th ,2015

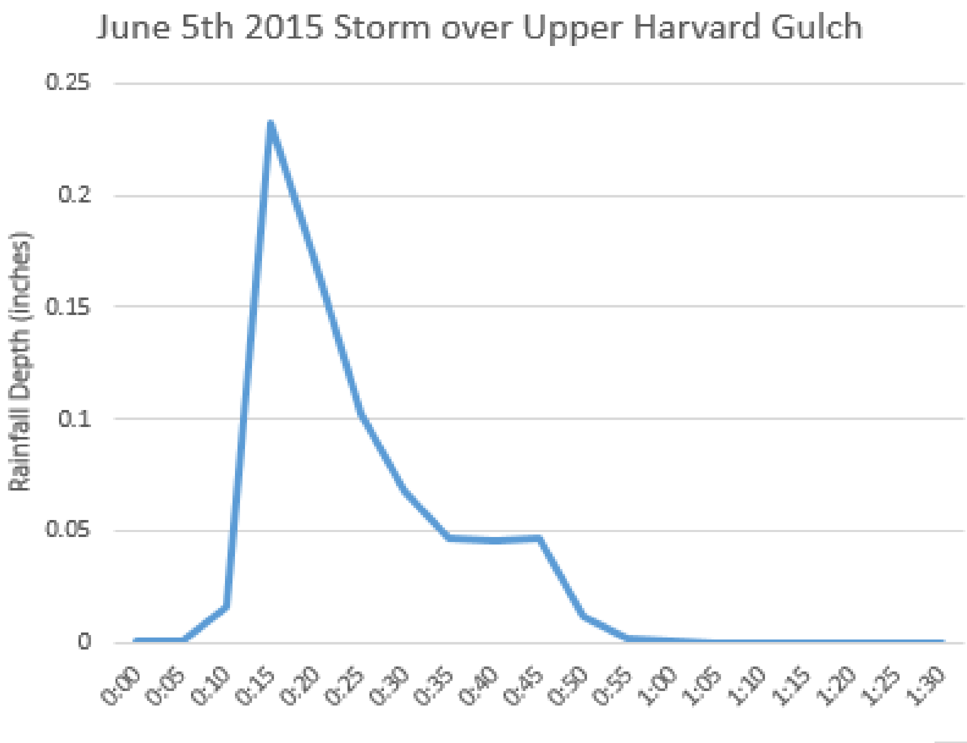

July 13th 2013 Storm over Upper Harvard Gulch

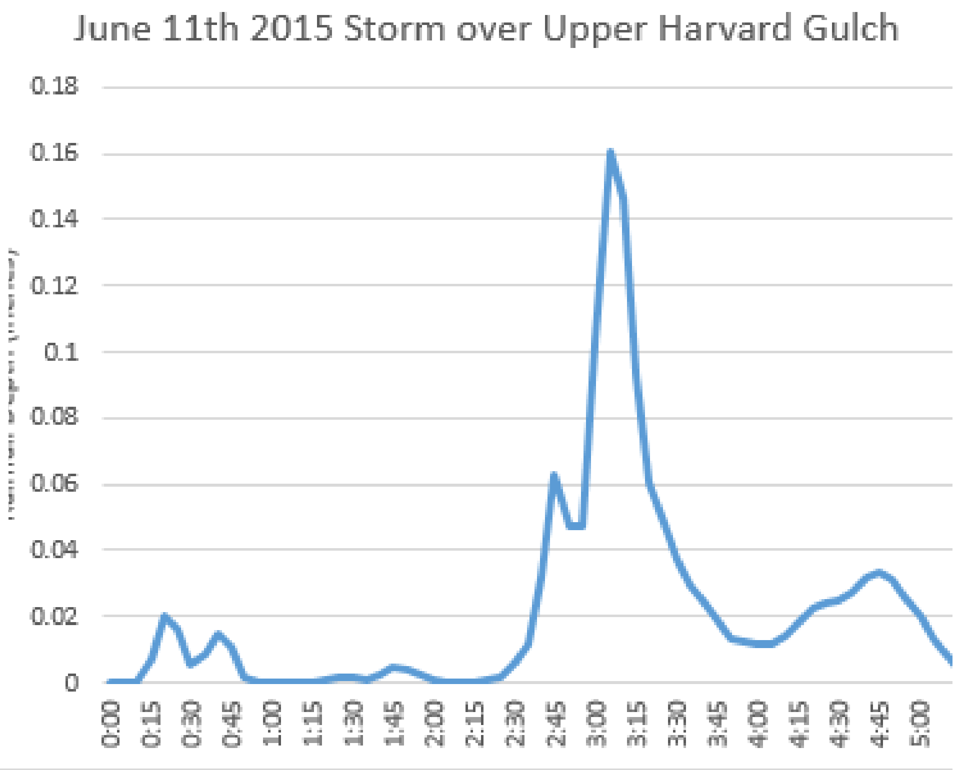

August 8th 2013 Storm over Upper Harvard Gulch

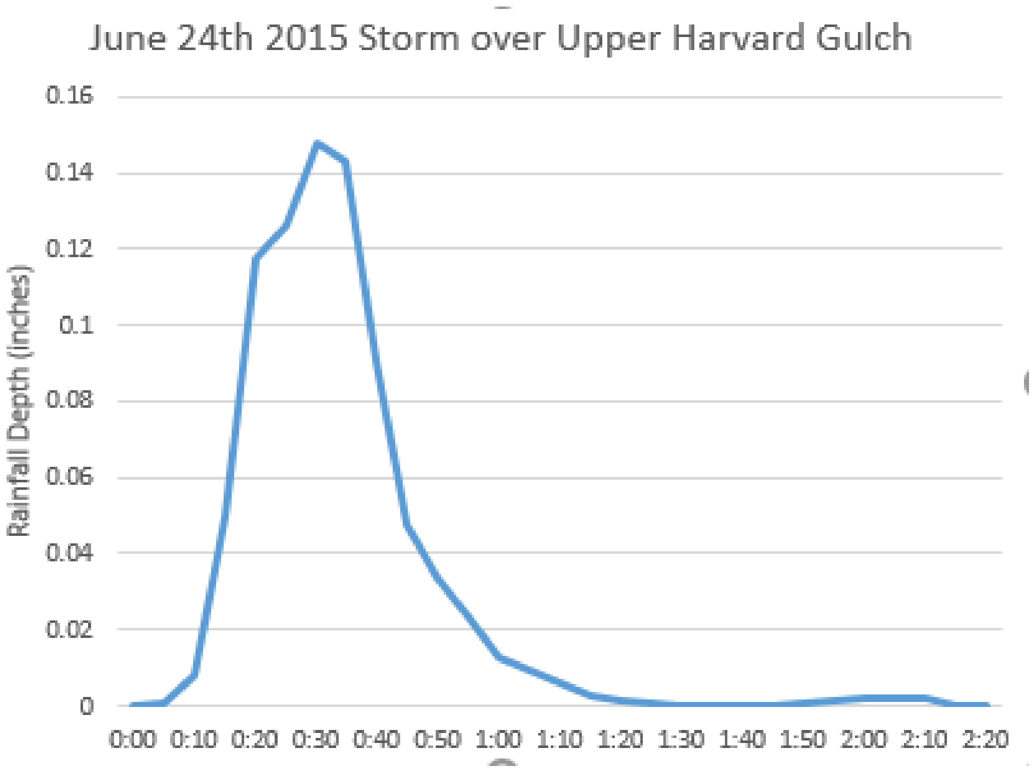

May 20th 2014 Storm over Upper Harvard Gulch

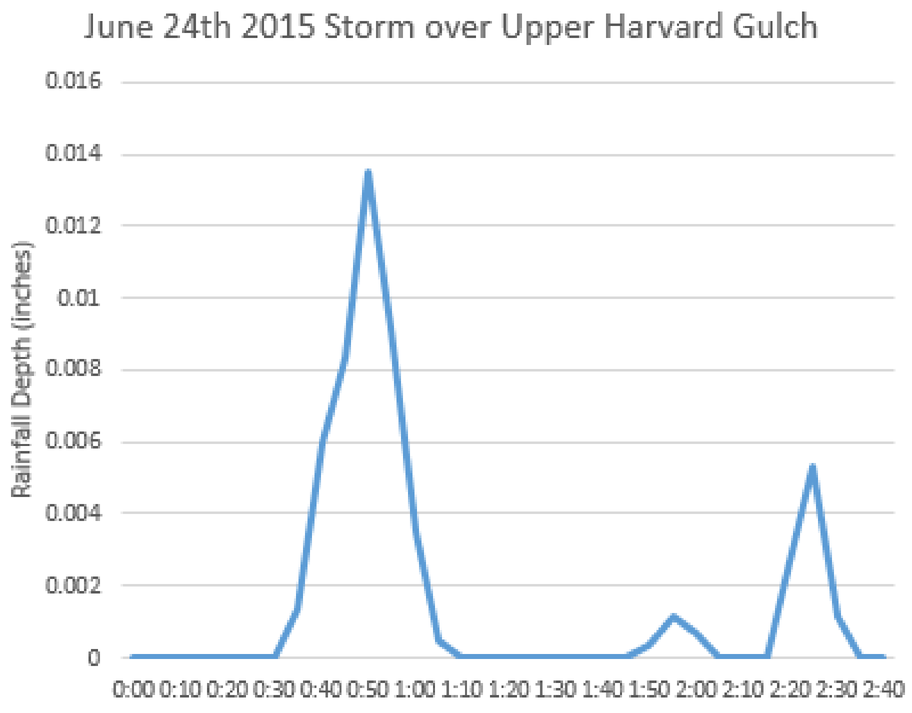

July 7th 2014 Storm over Upper Harvard Gulch

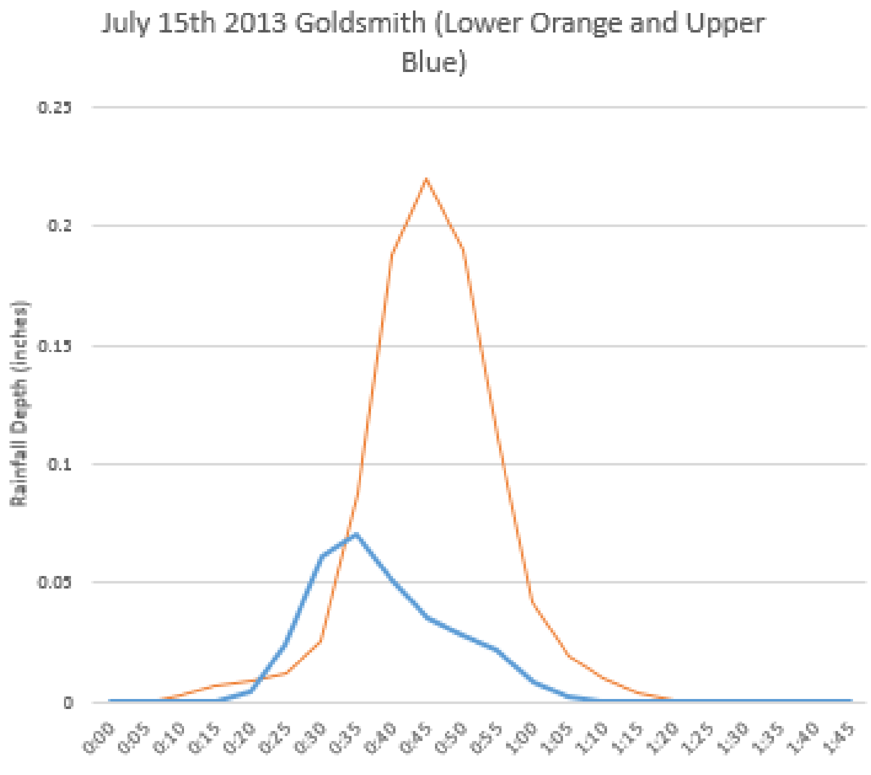
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis

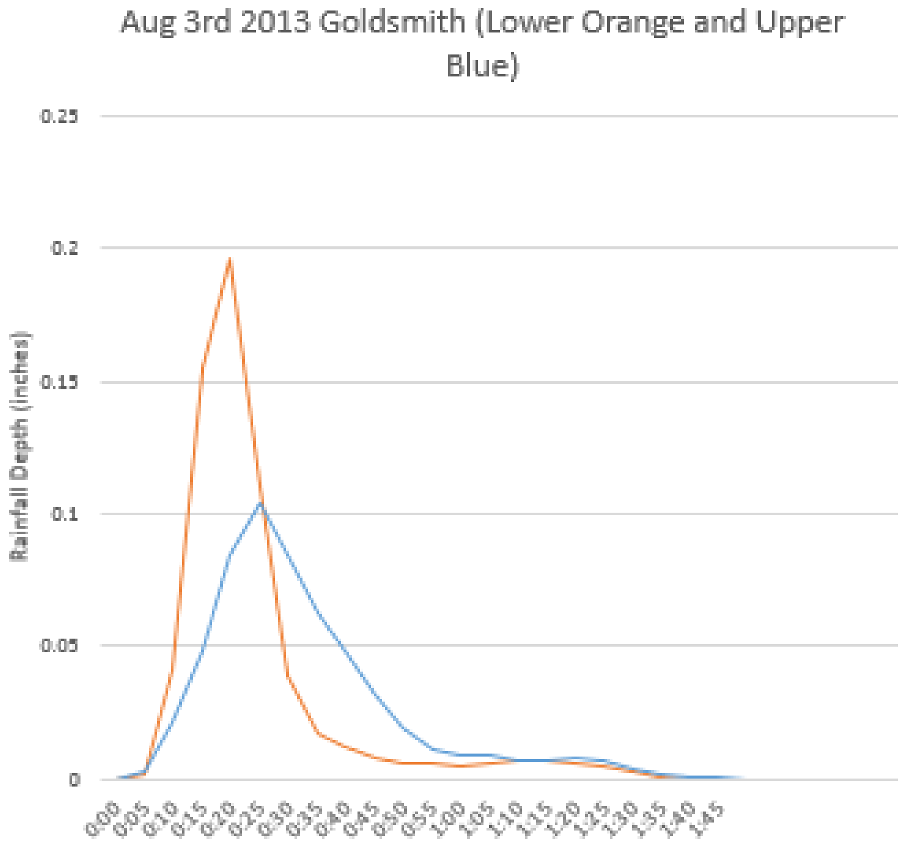

June 5th 2015 Storm over Upper Harvard Gulch


June 11th 2015 Storm over Upper Harvard Gulch

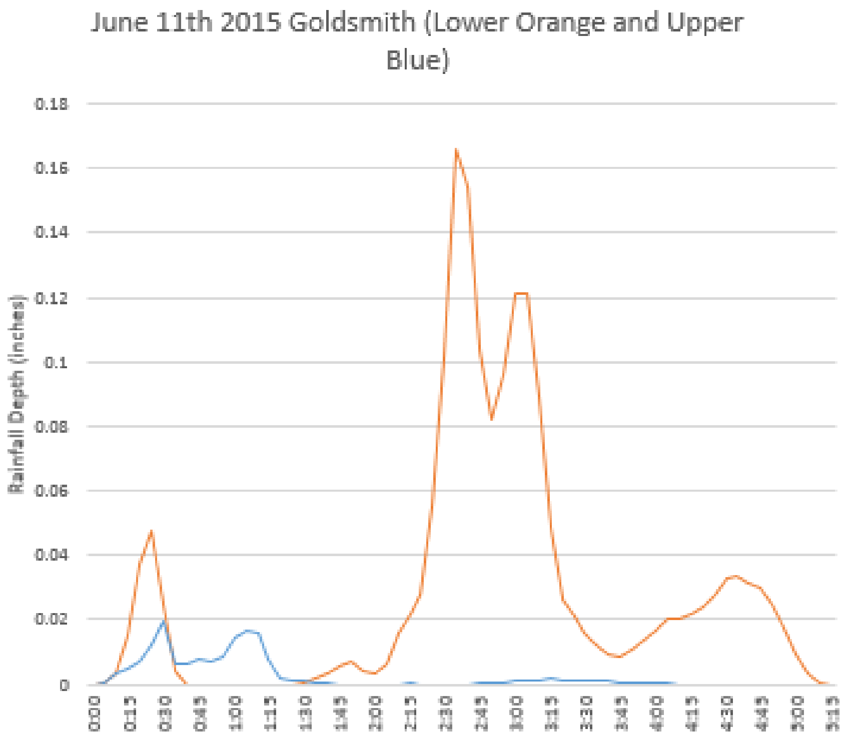

June 24th 2015 Storm over Upper Harvard Gulch

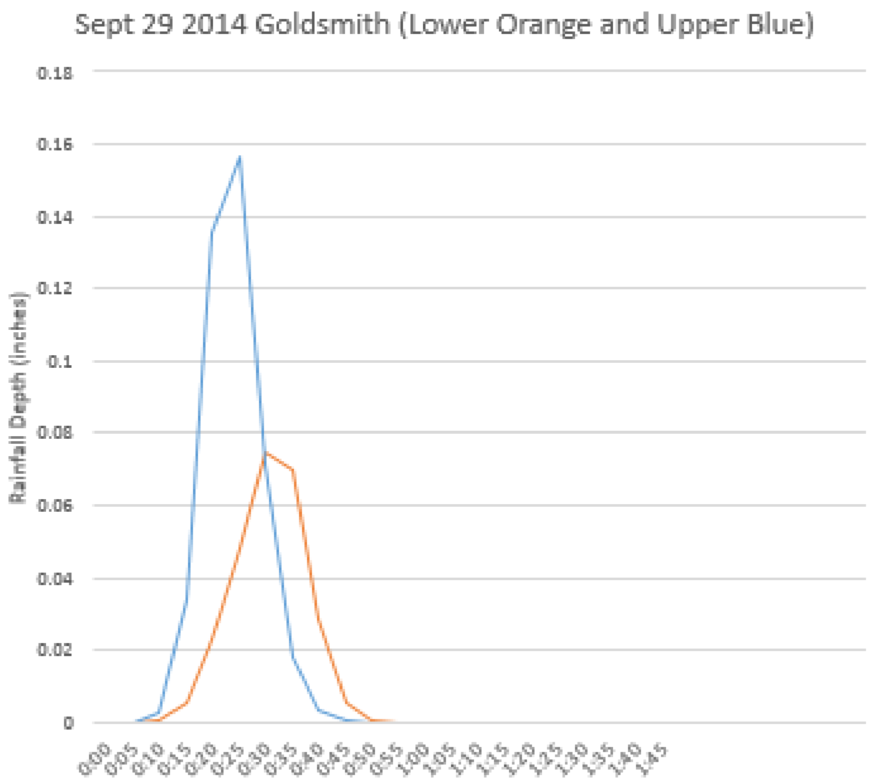

June 24th 2015 Storm over Upper Harvard Gulch

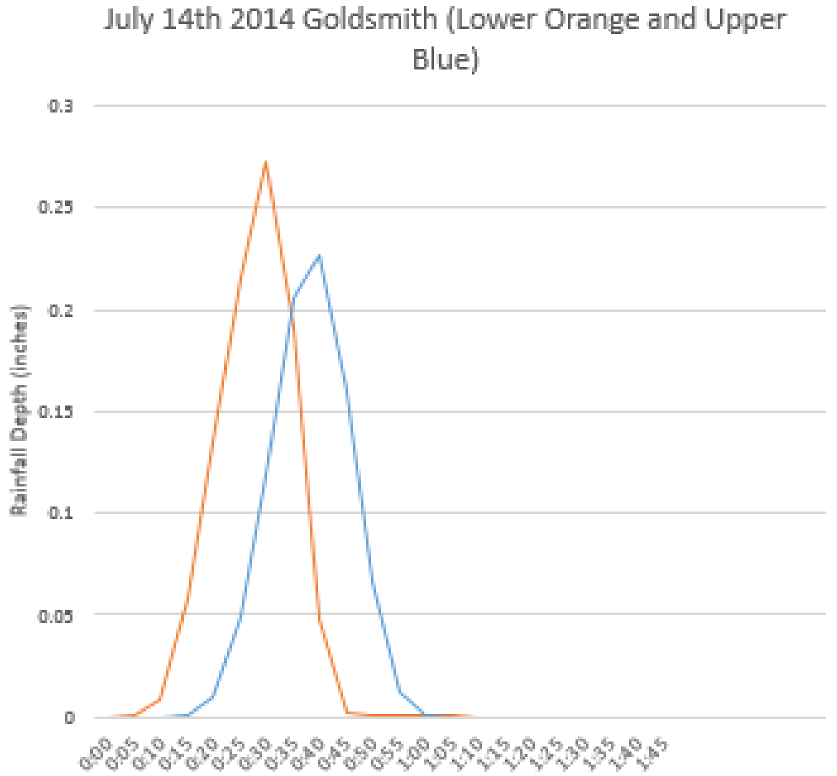

July 15th 2013 Goldsmith (Lower Orange and Upper Blue)

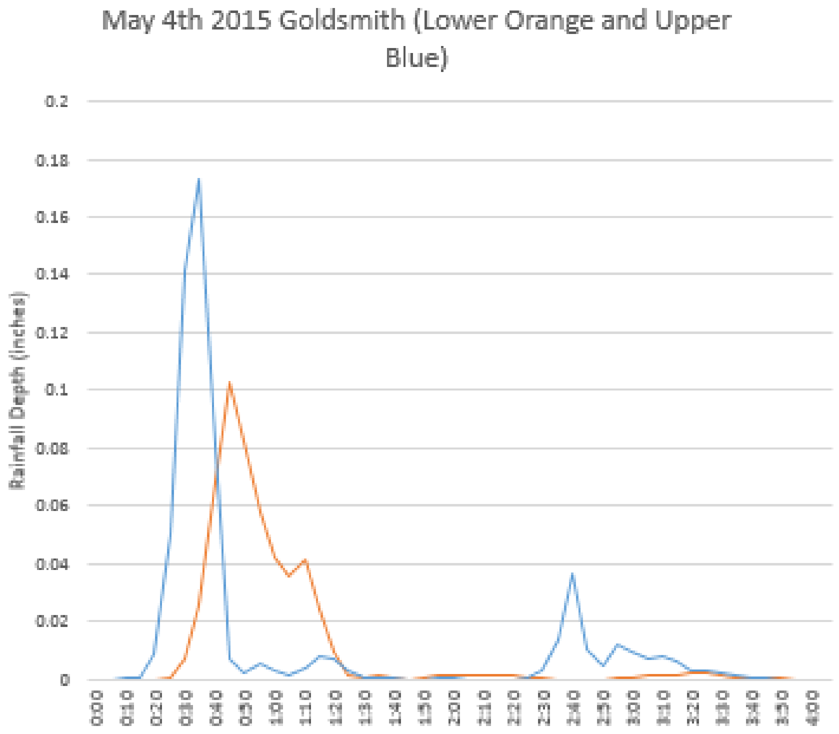

Aug 3rd 2013 Goldsmith (Lower Orange and Upper Blue)

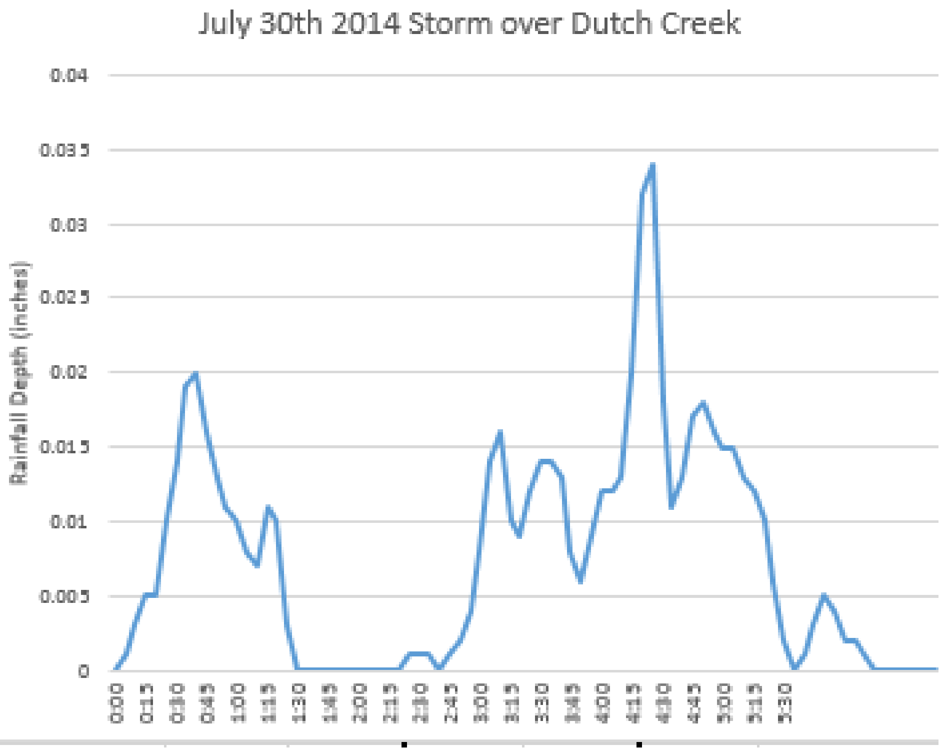
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis

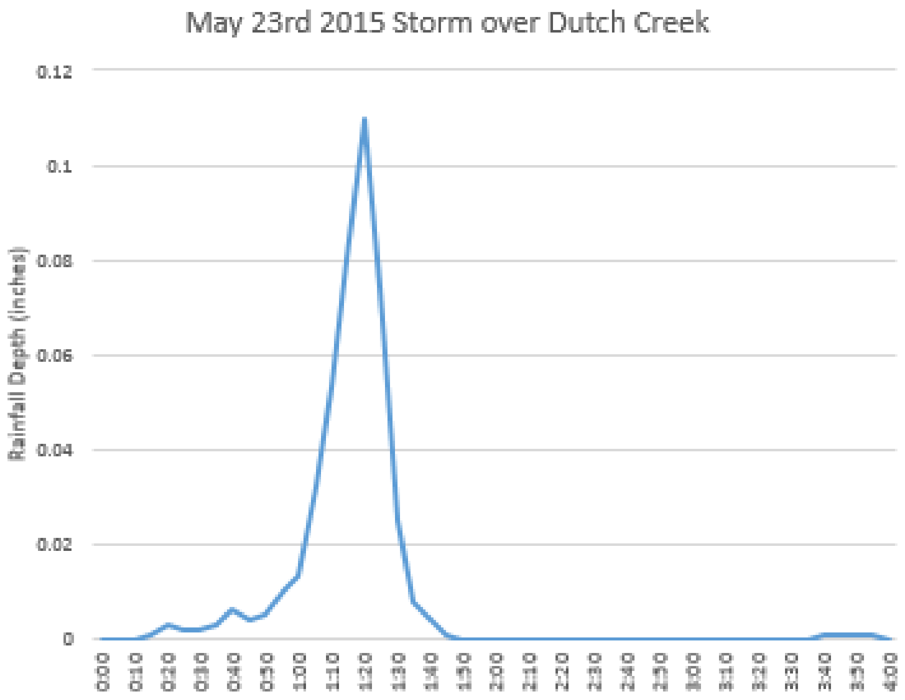

June 11th 2015 Goldsmith (Lower Orange and Upper Blue)


Sept 29 2014 Goldsmith (Lower Orange and Upper Blue)

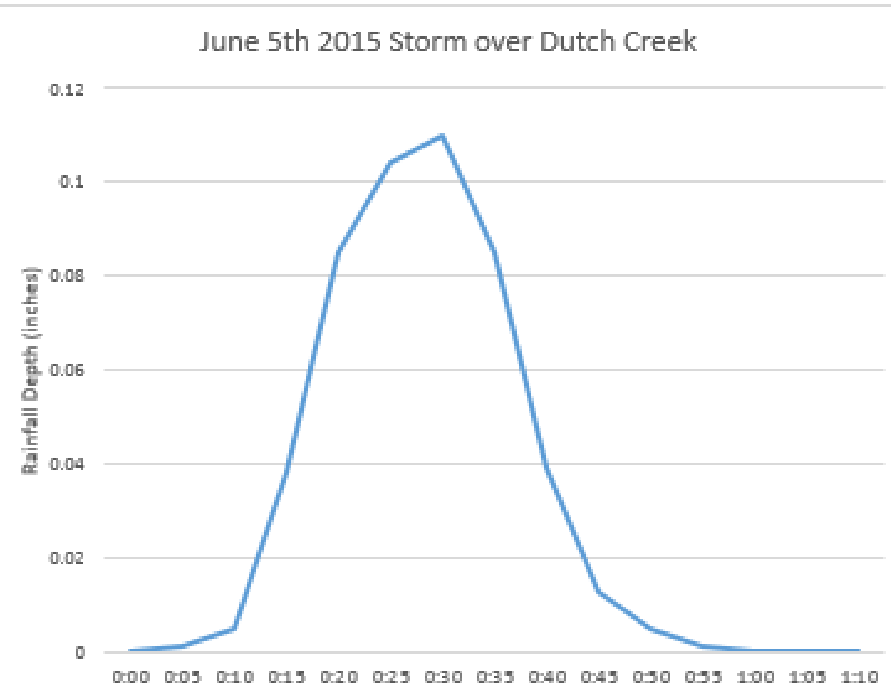

July 14th 2014 Goldsmith (Lower Orange and Upper Blue)

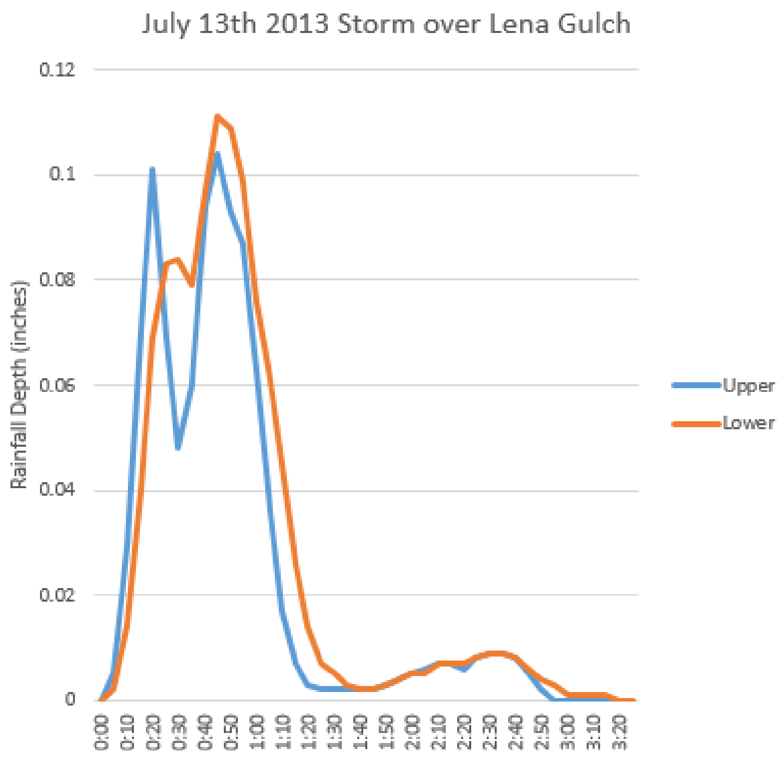

May 4th 2015 Goldsmith (Lower Orange and Upper Blue)

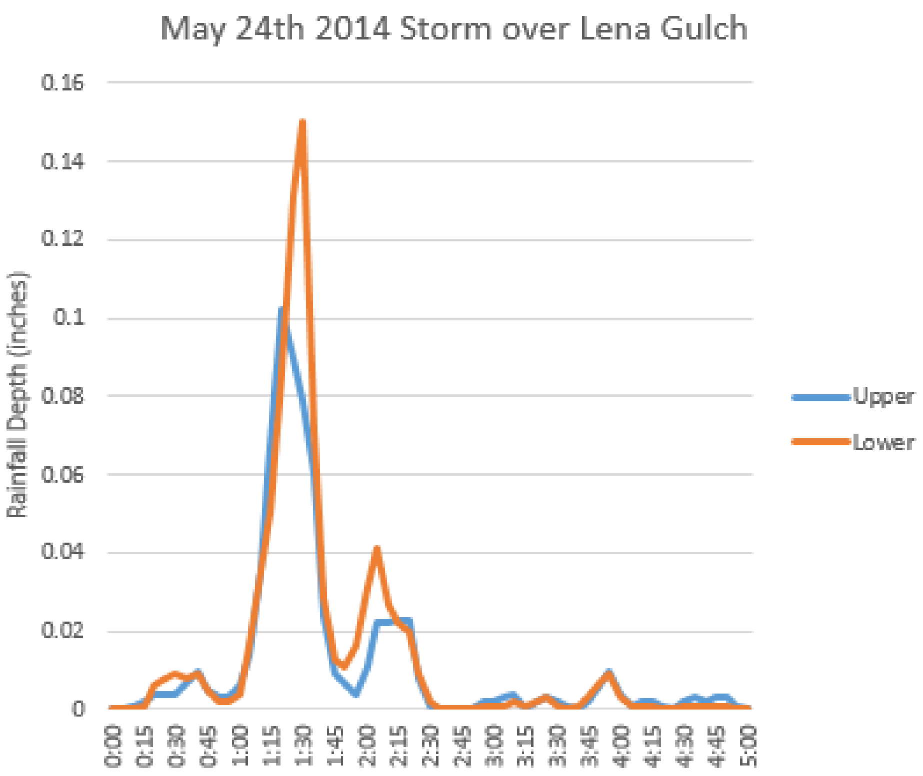

July 30th 2014 Storm over Dutch Creek

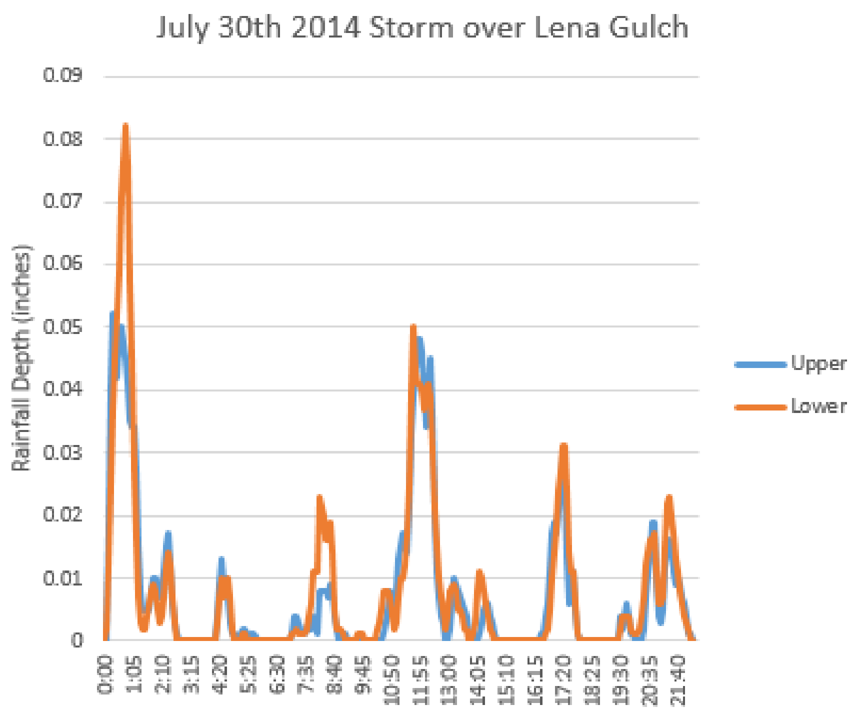

May 23rd 2015 Storm over Dutch Creek

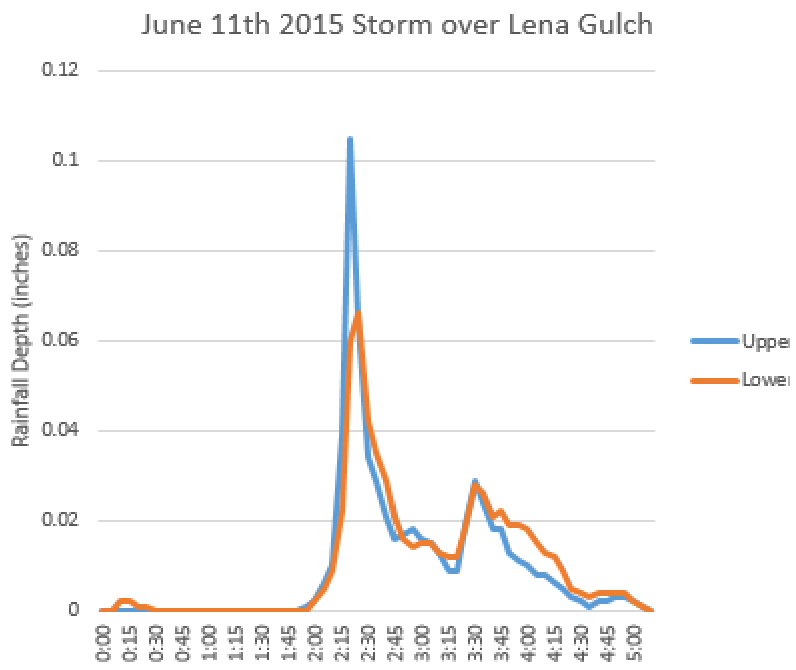
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis


June 5th 2015 Storm over Dutch Creek


July 13th 2013 Storm over Lena Gulch


May 24th 2014 Storm over Lena Gulch


July 30th 2014 Storm over Lena Gulch


June 11th 2015 Storm over Lena Gulch

Appendix B – CUHP Sub-Catchment Parameters for Select Basins

Summary of CUHP Input Parameters for Harvard Gulch (Version 1.5.1)

								Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in.hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con'ct Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
10	JUNCT_10	STORM1	0.030	0.057	0.161	0.012	32.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.66	0.18	28.26
20	JUNCT_20	STORM1	0.023	0.133	0.246	0.012	63.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	61.13
30	JUNCT_30	STORM1	0.016	0.114	0.246	0.012	41.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	38.30
40	JUNCT_40	STORM1	0.050	0.123	0.341	0.008	85.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.95	0.35	84.16
50	JUNCT_50	STORM1	0.020	0.133	0.265	0.010	62.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.28	59.60
60	JUNCT_60	STORM1	0.123	0.625	0.871	0.014	62.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	59.90
71	JUNCT_71	STORM1	0.038	0.203	0.365	0.021	74.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	72.00
72	JUNCT_72	STORM1	0.056	0.190	0.496	0.012	34.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.69	0.18	30.00
73	JUNCT_73	STORM1	0.034	0.189	0.354	0.022	62.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	60.00
80	JUNCT_80	STORM1	0.054	0.142	0.256	0.034	5.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.26
90	JUNCT_90	STORM1	0.038	0.152	0.331	0.015	19.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.39	0.13	15.14
95	JUNCT_95	STORM1	0.018	0.193	0.252	0.010	75.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	73.47
100	JUNCT_100	STORM1	0.019	0.152	0.256	0.007	75.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	73.16
110	JUNCT_110	STORM1	0.065	0.294	0.515	0.006	54.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.25	51.71
120	JUNCT_120	STORM1	0.060	0.152	0.398	0.014	51.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.23	47.73
130	JUNCT_130	STORM1	0.015	0.180	0.360	0.006	40.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.99
140	JUNCT_140	STORM1	0.110	0.265	0.549	0.007	72.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	70.44
150	JUNCT_150	STORM1	0.076	0.303	0.530	0.015	63.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	60.62
160	JUNCT_160	STORM1	0.031	0.170	0.360	0.006	68.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	66.28
170	JUNCT_170	STORM1	0.061	0.237	0.436	0.005	77.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.94	0.32	75.68
180	JUNCT_180	STORM1	0.104	0.246	0.540	0.012	57.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	54.36
190	JUNCT_190	STORM1	0.015	0.133	0.265	0.023	50.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.90
200	JUNCT_200	STORM1	0.082	0.246	0.492	0.017	60.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.06
210	JUNCT_210	STORM1	0.034	0.189	0.341	0.010	49.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.08
220	JUNCT_220	STORM1	0.017	0.133	0.246	0.017	50.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.80
230	JUNCT_230	STORM1	0.045	0.057	0.208	0.013	49.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.28
240	JUNCT_240	STORM1	0.071	0.208	0.454	0.011	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
250	JUNCT_250	STORM1	0.047	0.142	0.227	0.025	49.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	45.56
255	JUNCT_255	STORM1	0.033	0.189	0.445	0.014	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
260	SWMM_260	STORM1	0.033	0.170	0.322	0.026	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
270	JUNCT_270	STORM1	0.123	0.313	0.530	0.014	49.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	45.76
280	JUNCT_280	STORM1	0.074	0.152	0.379	0.012	67.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.29	65.14
290	JUNCT_290	STORM1	0.028	0.180	0.303	0.021	67.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	64.52
300	JUNCT_300	STORM1	0.071	0.208	0.483	0.021	69.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	66.39
310	JUNCT_310	STORM1	0.036	0.227	0.464	0.016	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
320	JUNCT_320	STORM1	0.122	0.237	0.625	0.014	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
330	JUNCT_330	STORM1	0.118	0.398	0.606	0.013	73.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	70.96
340	JUNCT_340	STORM1	0.090	0.133	0.303	0.015	22.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.46	0.14	18.24
350	JUNCT_350	STORM1	0.091	0.265	0.597	0.020	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
360	JUNCT_360	STORM1	0.091	0.208	0.644	0.020	50.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	47.01
370	JUNCT_370	STORM1	0.107	0.227	0.398	0.018	29.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	24.26
380	JUNCT_380	STORM1	0.087	0.170	0.417	0.014	21.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.42	0.13	16.63
390	JUNCT_390	STORM1	0.094	0.246	0.454	0.030	7.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.16	0.08	5.12
400	JUNCT_400	STORM1	0.200	0.379	0.663	0.015	25.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.52	0.15	21.05
410	JUNCT_410	STORM1	0.135	0.331	0.814	0.026	33.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.66	0.18	28.69
420	JUNCT_420	STORM1	0.124	0.227	0.407	0.025	22.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.45	0.14	18.04
430	JUNCT_430	STORM1	0.072	0.095	0.275	0.021	25.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.50	0.15	20.26
440	JUNCT_440	STORM1	0.162	0.218	1.022	0.016	34.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.68	0.18	29.56
450	JUNCT_450	STORM1	0.025	0.256	0.492	0.012	72.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.31	69.92
460	JUNCT_460	STORM1	0.015	0.133	0.227	0.012	49.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.49
470	JUNCT_470	STORM1	0.046	0.246	0.483	0.014	51.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.23	47.84

820	JUNCT_820	STORM1	0.069	0.161	0.430	0.028	60.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.35
821	JUNCT_821	STORM1	0.029	0.231	0.398	0.015	75.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	73.16
831	JUNCT_831	STORM1	0.053	0.143	0.362	0.030	50.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.70
832	JUNCT_832	STORM1	0.066	0.212	0.543	0.032	48.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.23	45.25
840	JUNCT_840	STORM1	0.091	0.265	0.502	0.023	45.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	42.26
860	JUNCT_860	STORM1	0.122	0.227	0.511	0.010	59.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	56.61
870	JUNCT_870	STORM1	0.062	0.095	0.364	0.006	49.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.18
871	JUNCT_871	STORM1	0.039	0.180	0.360	0.015	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
872	JUNCT_872	STORM1	0.014	0.104	0.237	0.026	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
880	JUNCT_880	STORM1	0.146	0.474	0.758	0.017	50.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	47.42
881	JUNCT_881	STORM1	0.062	0.538	0.711	0.027	61.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.28	58.88

Summary of CUHP Input Parameters for LDC ARAP (Version 1.5.1)

								Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in.hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con'ct Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
B1	1	STORM1	0.180	0.370	0.807	0.031	42.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	38.40
B2	2	STORM1	0.033	0.116	0.306	0.026	59.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	56.56
B3	3	STORM1	0.039	0.171	0.379	0.026	88.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.96	0.37	87.24
B5	5	STORM1	0.111	0.219	0.493	0.023	46.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.15
B6	6	STORM1	0.082	0.202	0.500	0.030	86.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.95	0.35	84.27
B7	7	STORM1	0.163	0.457	0.802	0.030	40.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.39
B8	8	STORM1	0.033	0.145	0.297	0.035	71.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	68.94
B9	9	STORM1	0.081	0.319	0.538	0.029	41.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	37.90
B10	10	STORM1	0.138	0.326	0.646	0.030	95.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.98	0.39	94.54
B11	11	STORM1	0.072	0.243	0.506	0.027	40.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.39
B12	12	STORM1	0.053	0.243	0.580	0.023	40.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.39
B13	13	STORM1	0.043	0.246	0.440	0.040	52.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.24	48.67
B14	14	STORM1	0.039	0.188	0.366	0.028	60.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.82
B15	15	STORM1	0.068	0.199	0.468	0.031	48.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	44.52
B16	16	STORM1	0.037	0.187	0.380	0.033	60.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.15
B17	17	STORM1	0.198	0.349	0.773	0.027	95.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.98	0.39	94.25
B18	18	STORM1	0.063	0.191	0.501	0.030	93.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.97	0.38	91.97

Summary of CUHP Input Parameters for Lena Gulch (Version 1.5.1)

								Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in.hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con'ct Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
1	JUNCT_1	UPPERSTORM1	0.119	0.208	0.455	0.060	10.0	0.40	0.10	6.00	2.70	0.0009	0.00	0.20	0.10	6.68
2	JUNCT_1	UPPERSTORM1	0.054	0.303	0.417	0.060	8.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.16	0.08	5.30
3	JUNCT_2	UPPERSTORM1	0.065	0.189	0.511	0.060	6.1	0.40	0.10	6.00	2.70	0.0009	0.00	0.12	0.06	3.91
4	JUNCT_3	UPPERSTORM1	0.098	0.360	0.663	0.060	1.3	0.40	0.10	3.00	1.08	0.0009	0.00	0.03	0.01	0.80
5	JUNCT_3	UPPERSTORM1	0.169	0.265	0.587	0.060	1.6	0.40	0.10	6.00	2.70	0.0009	0.00	0.03	0.02	0.96
6	JUNCT_4	UPPERSTORM1	0.156	0.341	0.795	0.060	3.5	0.40	0.10	3.00	1.08	0.0009	0.00	0.07	0.03	2.19
7	JUNCT_5	UPPERSTORM1	0.117	0.170	0.568	0.060	10.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.20	0.10	6.71
8	JUNCT_5	UPPERSTORM1	0.161	0.265	0.852	0.060	0.0	0.40	0.10	6.00	2.70	0.0009	0.00	0.00	0.00	0.02
9	JUNCT_6	UPPERSTORM1	0.127	0.417	0.758	0.060	10.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.20	0.10	6.71
10	JUNCT_6	UPPERSTORM1	0.151	0.417	0.890	0.060	10.0	0.40	0.10	6.00	2.70	0.0009	0.00	0.20	0.10	6.71
11	JUNCT_106	UPPERSTORM1	0.137	0.379	0.833	0.060	12.5	0.40	0.10	3.00	1.08	0.0009	0.00	0.25	0.11	8.78
12	JUNCT_7	UPPERSTORM1	0.103	0.246	0.720	0.060	0.7	0.40	0.10	3.00	1.08	0.0009	0.00	0.00	0.01	0.42
13	JUNCT_112	UPPERSTORM1	0.121	0.322	0.663	0.060	35.9	0.40	0.10	3.00	1.08	0.0009	0.00	0.72	0.19	31.62
14	JUNCT_8	UPPERSTORM1	0.140	0.303	0.701	0.060	0.3	0.40	0.10	3.00	1.08	0.0009	0.00	0.00	0.00	0.17
15	JUNCT_9	UPPERSTORM1	0.145	0.473	0.852	0.060	0.2	0.40	0.10	3.00	1.08	0.0009	0.00	0.00	0.00	0.11
16	JUNCT_12	UPPERSTORM1	0.106	0.322	0.587	0.060	4.6	0.40	0.10	3.00	1.08	0.0009	0.00	0.09	0.05	2.90
17	JUNCT_11	UPPERSTORM1	0.165	0.322	0.909	0.060	2.8	0.40	0.10	3.00	1.08	0.0009	0.00	0.06	0.03	1.75
18	JUNCT_10	UPPERSTORM1	0.109	0.511	0.966	0.060	20.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.40	0.13	15.52
19	JUNCT_10	UPPERSTORM1	0.144	0.470	0.852	0.060	1.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.02	0.01	0.64
20	JUNCT_10	UPPERSTORM1	0.086	0.246	0.606	0.060	30.8	0.40	0.10	3.00	1.08	0.0009	0.00	0.62	0.17	26.07
21	JUNCT_14	UPPERSTORM1	0.153	0.170	0.682	0.044	8.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.17	0.09	5.72
22	JUNCT_15	UPPERSTORM1	0.152	0.189	0.720	0.042	15.2	0.40	0.10	7.80	2.40	0.0009	0.00	0.30	0.12	11.11
23	JUNCT_17	UPPERSTORM1	0.098	0.360	0.720	0.053	41.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.81	0.20	38.02
24	JUNCT_16	UPPERSTORM1	0.186	0.303	0.606	0.060	9.1	0.40	0.10	7.80	2.40	0.0009	0.00	0.18	0.09	6.09
25	JUNCT_17	UPPERSTORM1	0.166	0.436	0.833	0.045	35.7	0.40	0.10	7.80	2.40	0.0009	0.00	0.71	0.19	31.44
26	JUNCT_20A	UPPERSTORM1	0.138	0.379	0.795	0.038	64.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.91	0.28	61.85
27	JUNCT_18	UPPERSTORM1	0.085	0.379	0.644	0.060	5.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.11	0.05	3.49
28	JUNCT_19	UPPERSTORM1	0.125	0.284	0.663	0.060	57.8	0.40	0.10	7.80	2.40	0.0009	0.00	0.89	0.26	54.83
29	JUNCT_20	UPPERSTORM1	0.122	0.246	0.625	0.048	62.2	0.40	0.10	7.80	2.40	0.0009	0.00	0.90	0.28	59.39
30	JUNCT_21	LOWERSTORM1	0.227	0.511	0.947	0.060	7.0	0.40	0.10	5.10	1.30	0.0009	0.00	0.14	0.07	4.56
31	JUNCT_21	LOWERSTORM1	0.131	0.455	0.795	0.060	0.1	0.40	0.10	5.10	1.30	0.0009	0.00	0.00	0.00	0.04
32	JUNCT_23	LOWERSTORM1	0.168	0.436	0.890	0.060	7.1	0.40	0.10	5.10	1.30	0.0009	0.00	0.14	0.07	4.60
33	JUNCT_22	LOWERSTORM1	0.116	0.398	0.814	0.060	7.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.16	0.08	5.17
34	JUNCT_22	LOWERSTORM1	0.138	0.379	0.871	0.060	13.5	0.40	0.10	5.10	1.30	0.0009	0.00	0.27	0.11	9.68
35	JUNCT_23	LOWERSTORM1	0.048	0.227	0.511	0.060	27.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.56	0.16	23.16
36	JUNCT_24	LOWERSTORM1	0.146	0.265	0.568	0.060	30.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.62	0.17	26.27
37	JUNCT_26	LOWERSTORM1	0.098	0.265	0.663	0.060	17.6	0.40	0.10	5.10	1.30	0.0009	0.00	0.35	0.12	13.32
38	JUNCT_26	LOWERSTORM1	0.092	0.303	0.777	0.060	13.0	0.40	0.10	5.10	1.30	0.0009	0.00	0.26	0.11	9.26
39	JUNCT_27	LOWERSTORM1	0.149	0.436	0.777	0.060	43.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.82	0.21	40.36
40	JUNCT_25	LOWERSTORM1	0.102	0.189	0.436	0.060	30.0	0.40	0.10	5.10	1.30	0.0009	0.00	0.60	0.17	25.31
41	JUNCT_28	LOWERSTORM1	0.144	0.303	0.511	0.044	41.7	0.40	0.10	5.10	1.30	0.0009	0.00	0.81	0.21	38.11
42	JUNCT_29	LOWERSTORM1	0.114	0.398	0.852	0.060	37.3	0.40	0.10	5.10	1.30	0.0009	0.00	0.75	0.19	33.25
43	JUNCT_29	LOWERSTORM1	0.116	0.208	0.625	0.061	41.9	0.40	0.10	7.80	2.40	0.0009	0.00	0.81	0.21	38.35
44	JUNCT_30	LOWERSTORM1	0.086	0.189	0.530	0.029	46.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.83	0.22	42.86
45	JUNCT_31	LOWERSTORM1	0.152	0.322	0.814	0.037	52.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.86	0.24	49.35
46	JUNCT_32	LOWERSTORM1	0.135	0.189	0.530	0.036	35.5	0.40	0.10	7.80	2.40	0.0009	0.00	0.71	0.19	31.24
47	JUNCT_40	LOWERSTORM1	0.150	0.625	0.928	0.029	46.9	0.40	0.10	7.80	2.40	0.0009	0.00	0.83	0.22	43.43
48	JUNCT_42	LOWERSTORM1	0.119	0.436	0.871	0.026	48.5	0.40	0.10	7.80	2.40	0.0009	0.00	0.84	0.23	45.08
49	JUNCT_42	LOWERSTORM1	0.069	0.322	0.606	0.025	47.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.84	0.22	44.14
50	JUNCT_33	LOWERSTORM1	0.155	0.379	0.852	0.036	31.1	0.40	0.10	7.80	2.40	0.0009	0.00	0.62	0.17	26.48
51	JUNCT_36	LOWERSTORM1	0.139	0.492	0.871	0.022	36.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.73	0.19	32.23

52	JUNCT_35	LOWERSTORM1	0.147	0.436	0.777	0.034	33.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.67	0.18	28.91
53	JUNCT_34	LOWERSTORM1	0.095	0.133	0.473	0.032	26.2	0.40	0.10	7.80	2.40	0.0009	0.00	0.52	0.15	21.47
54	JUNCT_36	LOWERSTORM1	0.114	0.549	0.852	0.044	30.9	0.40	0.10	7.80	2.40	0.0009	0.00	0.62	0.17	26.21
55	JUNCT_37	LOWERSTORM1	0.160	0.227	0.625	0.060	0.4	0.40	0.10	3.66	0.84	0.0009	0.00	0.00	0.00	0.25
56	JUNCT_38	LOWERSTORM1	0.093	0.303	0.625	0.048	8.7	0.40	0.10	3.66	0.84	0.0009	0.00	0.17	0.09	5.77
57	JUNCT_39	LOWERSTORM1	0.140	0.417	0.852	0.053	17.4	0.40	0.10	3.66	0.84	0.0009	0.00	0.35	0.12	13.08
58	JUNCT_41	LOWERSTORM1	0.117	0.265	0.625	0.048	1.0	0.40	0.10	3.66	0.84	0.0009	0.00	0.02	0.01	0.64
59	JUNCT_139	LOWERSTORM1	0.074	0.284	0.625	0.060	11.8	0.40	0.10	3.66	0.84	0.0009	0.00	0.24	0.11	8.19
60	JUNCT_42	LOWERSTORM1	0.122	0.549	0.795	0.048	22.4	0.40	0.10	3.66	0.84	0.0009	0.00	0.45	0.14	17.72
61	JUNCT_43	LOWERSTORM1	0.101	0.189	0.455	0.033	10.0	0.40	0.10	3.66	0.84	0.0009	0.00	0.20	0.10	6.71
62	JUNCT_45	LOWERSTORM1	0.182	0.511	0.852	0.044	26.9	0.40	0.10	3.66	0.84	0.0009	0.00	0.54	0.16	22.17
63	JUNCT_44	LOWERSTORM1	0.047	0.208	0.417	0.036	10.0	0.40	0.10	3.66	0.84	0.0009	0.00	0.20	0.10	6.71
64	JUNCT_45	LOWERSTORM1	0.195	0.417	0.777	0.049	41.3	0.40	0.10	3.66	0.84	0.0009	0.00	0.81	0.20	37.68
65	JUNCT_46	LOWERSTORM1	0.153	0.492	0.966	0.055	34.8	0.40	0.10	3.18	0.72	0.0009	0.00	0.70	0.18	30.48
66	JUNCT_141	LOWERSTORM1	0.115	0.189	0.568	0.053	49.2	0.40	0.10	4.68	1.26	0.0009	0.00	0.85	0.23	45.78
67	JUNCT_42	LOWERSTORM1	0.137	0.492	0.890	0.026	57.8	0.40	0.10	4.68	1.26	0.0009	0.00	0.89	0.26	54.81
68	JUNCT_46	LOWERSTORM1	0.176	0.606	0.966	0.035	60.1	0.40	0.10	4.68	1.26	0.0009	0.00	0.90	0.27	57.25
69	JUNCT_47	LOWERSTORM1	0.123	0.246	0.663	0.034	50.1	0.40	0.10	4.68	1.26	0.0009	0.00	0.85	0.23	46.69
70	JUNCT_48	LOWERSTORM1	0.168	0.379	0.758	0.025	37.2	0.40	0.10	4.68	1.26	0.0009	0.00	0.74	0.19	33.17
71	JUNCT_49	LOWERSTORM1	0.109	0.170	0.568	0.040	22.4	0.40	0.10	4.68	1.26	0.0009	0.00	0.45	0.14	17.73
73	JUNCT_46	LOWERSTORM1	0.126	0.284	0.682	0.028	64.6	0.40	0.10	4.68	1.26	0.0009	0.00	0.91	0.28	61.87
74	JUNCT_49	LOWERSTORM1	0.125	0.303	0.492	0.023	27.4	0.40	0.10	4.68	1.26	0.0009	0.00	0.55	0.16	22.60

Summary of CUHP Input Parameters for Goldsmith Gulch (Version 1.5.1)

								Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in.hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con'ct Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
1	101	STORM1	0.089	0.318	0.817	0.012	70.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	68.89
2	102	STORM1	0.139	0.683	0.975	0.013	60.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.26
3	103	STORM1	0.240	0.232	0.606	0.014	28.8	0.35	0.06	3.00	0.50	0.0018	0.00	0.58	0.17	25.56
4	104	STORM1	0.157	0.445	0.846	0.013	33.6	0.35	0.05	3.00	0.50	0.0018	0.00	0.67	0.18	30.56
5	105	STORM1	0.155	0.369	0.631	0.023	48.4	0.35	0.07	3.00	0.50	0.0018	0.00	0.84	0.23	46.09
6	106	STORM1	0.085	0.151	0.361	0.011	25.9	0.35	0.07	3.00	0.50	0.0018	0.00	0.52	0.15	22.57
7	107	STORM1	0.142	0.202	0.449	0.011	34.7	0.35	0.07	3.00	0.50	0.0018	0.00	0.69	0.18	31.76
8	108	STORM1	0.137	0.216	0.964	0.008	30.6	0.35	0.07	3.00	0.50	0.0018	0.00	0.61	0.17	27.36
9	109	STORM1	0.225	0.521	0.928	0.020	33.7	0.35	0.06	3.00	0.50	0.0018	0.00	0.67	0.18	30.60
10	110	STORM1	0.180	0.240	0.696	0.012	34.5	0.35	0.07	3.00	0.50	0.0018	0.00	0.69	0.18	31.54
11	111	STORM1	0.067	0.320	0.428	0.009	53.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.24	51.26
12	112	STORM1	0.119	0.285	0.467	0.014	61.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	59.18
13	113	STORM1	0.050	0.302	0.763	0.003	51.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.23	48.82
14	114	STORM1	0.155	0.399	0.748	0.004	57.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	55.56
15	115	STORM1	0.120	0.261	0.601	0.007	46.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	44.30
16	116	STORM1	0.132	0.214	0.547	0.009	58.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	56.45
17	117	STORM1	0.153	0.206	0.914	0.013	34.1	0.35	0.05	3.00	0.50	0.0018	0.00	0.68	0.18	31.09
18	118	STORM1	0.089	0.208	0.639	0.014	35.2	0.35	0.07	3.00	0.50	0.0018	0.00	0.70	0.19	32.31
19	119	STORM1	0.060	0.173	0.361	0.004	61.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.28	59.80
20	120	STORM1	0.163	0.217	0.593	0.016	61.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	59.41
21	121	STORM1	0.209	0.533	0.856	0.006	45.8	0.35	0.08	3.00	0.50	0.0018	0.00	0.83	0.22	43.47
22	122	STORM1	0.172	0.136	0.768	0.011	51.4	0.35	0.08	3.00	0.50	0.0018	0.00	0.86	0.24	49.14
23	123	STORM1U	0.215	0.438	0.975	0.011	61.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.42
24	124	STORM1U	0.163	0.479	0.656	0.004	59.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	56.91
25	125	STORM1U	0.129	0.432	1.133	0.004	55.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.88	0.25	52.36
26	126	STORM1U	0.153	0.530	0.814	0.011	45.1	0.35	0.07	3.00	0.50	0.0018	0.00	0.83	0.22	41.58
27	127	STORM1U	0.159	0.475	0.979	0.010	54.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.25	50.90
28	128	STORM1U	0.166	0.193	0.636	0.016	25.2	0.35	0.05	3.00	0.50	0.0018	0.00	0.50	0.15	20.45
29	129	STORM1U	0.060	0.154	0.441	0.006	29.2	0.35	0.05	3.00	0.50	0.0018	0.00	0.58	0.17	24.45
30	130	STORM1U	0.183	0.396	0.709	0.011	22.4	0.35	0.05	3.00	0.50	0.0018	0.00	0.45	0.14	17.78
31	131	STORM1U	0.057	0.196	0.518	0.021	30.1	0.35	0.05	3.00	0.50	0.0018	0.00	0.60	0.17	25.42
32	132	STORM1U	0.103	0.367	0.625	0.007	57.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	54.55
33	133	STORM1U	0.217	0.246	0.786	0.007	32.7	0.35	0.05	3.00	0.50	0.0018	0.00	0.65	0.18	28.13
34	134	STORM1U	0.069	0.283	0.599	0.016	37.4	0.35	0.05	3.00	0.50	0.0018	0.00	0.75	0.19	33.35
35	135	STORM1U	0.113	0.194	0.669	0.020	38.3	0.35	0.05	3.00	0.50	0.0018	0.00	0.77	0.19	34.42
36	136	STORM1U	0.101	0.300	0.687	0.001	34.7	0.35	0.07	3.00	0.50	0.0018	0.00	0.69	0.18	30.30
37	137	STORM1U	0.158	0.292	0.724	0.003	34.1	0.35	0.07	3.00	0.50	0.0018	0.00	0.68	0.18	29.65
38	138	STORM1U	0.044	0.210	0.334	0.022	76.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	74.36
39	139	STORM1U	0.029	0.257	0.534	0.008	57.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	54.55
40	140	STORM1U	0.135	0.452	0.777	0.011	62.2	0.35	0.08	3.00	0.50	0.0018	0.00	0.90	0.28	59.41
41	141	STORM1U	0.171	0.441	0.986	0.032	66.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	63.68
42	142	STORM1U	0.075	0.045	0.364	0.020	73.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	71.21

Summary of CUHP Input Parameters for Dutch Creek (Version 1.5.1)

								Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in.hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con'ct Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
CC1	CC1	STORM1	0.166	0.440	0.622	0.019	42.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	39.99
CC2	CC2	STORM1	0.260	0.198	0.751	0.019	45.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.60
CC3	CC3	STORM1	0.364	0.310	0.777	0.019	34.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.69	0.18	32.23
CC4	CC4	STORM1	0.233	0.352	0.551	0.029	31.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.62	0.17	28.29
CC5	CC5	STORM1	0.496	0.414	1.418	0.015	59.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.27	57.34
CC6	CC6	STORM1	0.151	0.387	0.852	0.009	59.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.49
CC7	CC7	STORM1	0.123	0.230	0.640	0.015	65.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	63.53
CC8	CC8	STORM1	0.216	0.476	0.965	0.020	48.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.23	46.61
CC9	CC9	STORM1	0.234	0.426	0.902	0.021	42.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	40.30
CC10	CC10	STORM1	0.252	0.533	0.994	0.019	59.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.04
CC11	CC11	STORM1	0.343	0.415	1.019	0.020	41.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.49
CC12	CC12	STORM1	0.435	0.506	1.090	0.021	39.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.78	0.20	36.94
CC13	CC13	STORM1	0.355	0.297	1.218	0.026	39.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.78	0.20	37.03
CCN1	CCN1	STORM1	0.015	0.079	0.185	0.031	58.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	56.69
CCN2	CCN2	STORM1	0.117	0.366	0.802	0.026	43.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.82	0.21	41.68
CCN3	CCN3	STORM1	0.279	0.463	0.930	0.017	47.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	45.28
CCN4	CCN4	STORM1	0.279	0.285	0.812	0.019	45.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.71
CCN5	CCN5	STORM1	0.046	0.220	0.431	0.025	37.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.74	0.19	34.68
DC1	DC1	STORM1	0.299	0.626	1.434	0.011	28.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.56	0.16	25.19
DC2	DC2	STORM1	0.255	0.451	0.877	0.018	35.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.71	0.19	33.03
DC3	DC3	STORM1	0.343	0.421	1.008	0.015	41.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.29
DC4	DC4	STORM1	0.134	0.299	0.712	0.023	42.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	40.19
DC5	DC5	STORM1	0.172	0.281	0.771	0.012	41.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.46
DC6	DC6	STORM1	0.131	0.315	0.387	0.020	53.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.24	51.71
DC7	DC7	STORM1	0.166	0.205	0.620	0.016	52.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.24	51.06
DC8	DC8	STORM1	0.274	0.406	1.104	0.022	47.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	45.28
DC9	DC9	STORM1	0.257	0.289	0.820	0.025	35.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.71	0.19	33.25
DC10	DC10	STORM1	0.166	0.202	0.546	0.041	31.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.63	0.17	28.60
DC11	DC11	STORM1	0.113	0.150	0.504	0.032	32.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.65	0.18	29.83
DC12	DC12	STORM1	0.131	0.299	0.488	0.038	18.2	0.35	0.10	4.00	0.55	0.0018	0.00	0.36	0.12	15.27
DC13	DC13	STORM1	0.155	0.532	1.167	0.028	41.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.28
DC14	DC14	STORM1	0.349	0.639	1.486	0.034	12.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.24	0.11	10.09
DC15	DC15	STORM1	0.363	0.472	0.984	0.036	34.2	0.35	0.10	4.50	0.60	0.0018	0.00	0.68	0.18	30.95
DC16	DC16	STORM1	0.467	0.870	1.669	0.025	9.9	0.35	0.10	4.00	0.55	0.0018	0.00	0.20	0.10	7.77
DC17	DC17	STORM1	0.281	0.598	1.027	0.039	21.7	0.35	0.10	4.00	0.55	0.0018	0.00	0.43	0.14	18.59
DC18	DC18	STORM1	0.227	0.330	0.836	0.054	5.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.95
DC19	DC19	STORM1	0.272	0.364	0.908	0.038	5.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.95
DC20	DC20	STORM1	0.089	0.170	0.459	0.038	17.0	0.35	0.10	4.00	0.55	0.0018	0.00	0.34	0.12	14.20
DC21	DC21	STORM1	0.169	0.295	0.568	0.056	12.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.25	0.11	10.15
DC22	DC22	STORM1	0.180	0.479	0.771	0.046	5.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.95
DC23	DC23	STORM1	0.546	0.796	1.805	0.051	31.7	0.35	0.10	4.00	0.55	0.0018	0.00	0.63	0.18	28.63
DC24	DC24	STORM1	0.211	0.604	1.206	0.049	19.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.38	0.13	16.56
DC25	DC25	STORM1	0.355	0.758	1.419	0.058	16.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.32	0.12	13.74
DC26	DC26	STORM1	0.364	0.724	1.384	0.061	6.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.12	0.06	4.82
DC27	DC27	STORM1	0.509	0.845	1.611	0.061	9.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.19	0.09	7.62
DCN1	DCN1	STORM1	0.221	0.463	0.913	0.034	29.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	26.39
DCN2	DCN2	STORM1	0.231	0.392	0.985	0.039	23.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.46	0.14	20.34
DCT1	DCT1	STORM1	0.157	0.484	1.015	0.032	30.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.61	0.17	27.89
LG1	LG1	STORM1	0.045	0.210	0.389	0.022	41.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	39.65
LG2	LG2	STORM1	0.045	0.190	0.396	0.032	37.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.75	0.19	35.29
LG3	LG3	STORM1	0.194	0.410	0.726	0.015	29.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	26.47

LG4	LG4	STORM1	0.118	0.305	0.555	0.017	35.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.70	0.19	32.51
LG5	LG5	STORM1	0.104	0.205	0.538	0.022	45.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.05
LG6	LG6	STORM1	0.317	0.490	1.009	0.019	42.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	40.10
LG7	LG7	STORM1	0.258	0.520	0.974	0.026	40.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	38.17
LG8	LG8	STORM1	0.411	0.560	1.176	0.029	37.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.76	0.19	35.53
LG9	LG9	STORM1	0.045	0.070	0.224	0.017	47.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	45.13
LG10	LG10	STORM1	0.280	0.518	1.196	0.023	46.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	44.63
LG11	LG11	STORM1	0.191	0.364	0.771	0.026	37.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.74	0.19	34.66
LG12	LG12	STORM1	0.204	0.327	0.886	0.026	39.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.79	0.20	37.29
LGN1	LGN1	STORM1	0.316	0.313	0.882	0.020	73.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	72.26
LGN2	LGN2	STORM1	0.335	0.625	1.282	0.024	65.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	63.54
LGN3	LGN3	STORM1	0.314	0.527	1.090	0.023	46.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	44.62
LGN4	LGN4	STORM1	0.188	0.372	0.634	0.035	68.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	67.09
TL1	TL1	STORM1	0.200	0.533	0.975	0.018	40.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	38.47
TL2	TL2	STORM1	0.142	0.238	0.668	0.018	44.8	0.35	0.10	4.00	0.55	0.0018	0.00	0.82	0.21	42.43
TL3	TL3	STORM1	0.271	0.569	1.088	0.016	40.0	0.35	0.10	4.00	0.55	0.0018	0.00	0.80	0.20	37.60

Summary of CUHP Input Parameters for Dry Gulch (Version 1.4.4 and Version 1.5.4)

								Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in.hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con'ct Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
8B	8B	100	0.172	0.251	0.974	0.021	55.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.88	0.25	54.35
7B	7B	100	0.059	0.315	0.775	0.013	60.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	60.02
1B	1B	100	0.163	0.117	0.768	0.018	42.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	41.70
6B	6B	100	0.141	0.308	1.031	0.013	64.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	63.55
5B	5B	100	0.213	0.298	1.032	0.017	65.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	64.70
3B	3B	100	0.147	0.428	0.814	0.015	48.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	47.27
14B	14B	100	0.266	0.347	1.142	0.018	45.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	45.00
12B	12B	100	0.164	0.557	1.121	0.021	51.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.24	50.83
10B	10B	100	0.084	0.192	0.604	0.030	62.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	61.90
2B	2B	100	0.278	0.435	1.350	0.018	24.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.48	0.15	22.98
4B	4B	100	0.168	0.409	1.152	0.022	29.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	27.89
18B	18B	100	0.152	0.391	0.935	0.016	43.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.82	0.21	42.81
17B	17B	100	0.185	0.377	1.284	0.015	42.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	41.26
9B	9B	100	0.255	0.353	0.865	0.012	62.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	61.93
13B	13B	100	0.117	0.187	0.917	0.014	59.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.23
11B	11B	100	0.184	0.480	0.989	0.013	71.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.31	71.23
16B	16B	100	0.235	0.448	0.941	0.014	43.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.82	0.21	42.53
15B	15B	100	0.140	0.282	0.922	0.010	38.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.77	0.20	37.63
19B	19B	100	0.073	0.308	0.636	0.015	66.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	65.32
21B	21B	100	0.145	0.308	0.715	0.015	30.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.60	0.17	28.76
20B	20B	100	0.122	0.198	0.649	0.026	32.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.64	0.18	30.79
22B	22B	100	0.151	0.276	0.786	0.023	35.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.70	0.19	33.85

Appendix C – Addressed Comments from June 2016 Draft Summary Report

RESPONSE TO COMMENTS FROM CUHP RECALIBRATION SUMMARY REPORT SENT IN JUNE OF 2016

MAJOR COMMENTS AND RESPONSES:

Urbonas: Looking at the comparisons I see much overlap with the SWMM routing analysis Derek and I did for you for the peak flow comparisons.

a. I am not convinced that the gage data used, especially in the few cases where there are significant differences, are always credible.

b. There is no discussion in the report that the timing and proper routing of the sub-hydrographs from individual sub-catchments was considered, or used, in the SWMM model.

c. In the report's tables, many of the peaks increase when going from a single large catchment to many small sub-catchments. This is exactly what was explored earlier and, at least to me, implies that the routing protocols used with the current CUHP model is still the reason for the increases in downstream peaks.

Response: The previous report prepared by Rapp and Urbonas (2014) was reviewed as part of this study. Models used in this report were from the MDP models developed for the District by the District's consultants and were assumed to be developed per the District's standards. Additionally, one of the first recommendations from this project was to apply routing methods that would not compound the peak flows as they move downstream, i.e. applying the Dynamic Wave for routing. This recommendation was not carried forward but was considered viable.

The Sept Version of the report has been updated to include more discussion on the proper routing and timing of hydrographs.

Baxter: The origin and characteristics of this rainfall product should be given, especially since it is not generally available in the public domain. Suggested wording is as follows:

Gage-adjusted radar rainfall (GARR) is gridded rainfall at high spatial and temporal resolution. GARR is a combination of radar and rain gage data, that leverages the strength of both sensor measurements (Vieux, 2013). It was produced by Vieux & Associates, Inc. for the Urban Drainage and Flood Control District for use in their flood warning program. The GARR period of record extends from June 2013

Reference:

Vieux, 2013. Chapter 11 in *Hydrology and Floodplain Analysis.* by Bedient, Huber, and Vieux, Fifth Edition, Prentice-Hall, Inc., One Lake St., Upper Saddle River, NJ 07458. ISBN 0-13-256796-2.

Response: Thank you for the additional wording and reference, they will be incorporated into the report. If there is any more detail you feel should be added about the GARR derivation process, we will happily add it into our final report.

Baxter: When you calibrated the equations, are those the Ct and Cp coefficients in the Snyder method? Please clarify. Also, when running frequency storms and comparing to stream gage flow frequencies, there are several assumptions that must (should) be made such as duration and antecedent soil moisture. Was this done? Please improve the description of the calibration and which factors were considered.

Response: Yes, these peaking parameters are based on the Snyder Method, which is referenced later in the report on Page 4.

Antecedent storms were tested as part of this study. It was found that little to no difference in the CUHP results were produced. This is because CUHP applies a time dependent form of Horton's equation and infiltration capacity from the beginning of the storm is not carried forward in the model. As such, most storms experienced their peak by the time the decay curve was flattening out and becoming constant. As such, when storms earlier in the day, or week were considered, there was no difference between the two CUHP models. However, there was not a significant effort on analyzing the peak years from the gages and estimating the antecedent moisture conditions for those annual peaks. Within the Semi Arid Environment of Denver, CO, it is a relatively safe assumption that the soil capacity has regained itself over a short time in the summer months when our flash floods occur.

Rapp: It would be nice to see a side-by-side comparison of the results (peak flows and hydrographs) for the existing model, an adjusted model to remove the study specific adjustments, and the proposed model. This would demonstrate whether the proposed model can adequately replace the need for study specific adjustments to Cp and Ct.

Response: Agreed. Hydrograph comparisons have been added and the frequency gages no include V 1.4.4 without adjusted Cp.

Rogers: I assume this includes both rainfall and stream gage data. How is gage data compared/related to storm frequency, especially the stream gage data? In other words, how do you know you are measuring a certain frequency storm event (eg. 10-year)?

Response: Gage data and flood frequency are related statistically based on annual exceedance probabilities which are most commonly estimated by the Log Pearson III method recommended in Bulletin 17B. The methodology does not include rainfall. Conversely, the Unit Hydrograph Method is calibrated from an array of storms, backed into a unit runoff and shape, then applied design rainfall storms that contain rainfall *depths* that are determined statically and distributed according to a design rainfall curve. The other option for calibration would have been to make smaller adjustments to the peaking parameters of CUHP and then modify the UDFCD design storm distribution. This route was not taken, but was considered and could have been equally justified.

Rapp: Will this investigation be done before releasing a new version of CUHP? The additional investigation may produce results that conflict with the approach being proposed in this report.

Response: It is my recommendation to apply a separate method or unit graph for the mountains and not use CUHP in the mountain regions, or have a Mountain CUHP… at that point it would be wiser to have guidance for applying SWMM5 or Snyder in HMS for those regions than developing another specific model. This will likely not be completed under this study.

Rapp: The re-calibration study uses the NOAA Atlas 14 precipitation values which are known to be lower than the previous values used by the District. However, it is not clear if the NOAA Atlas 14 precipitation values were used for both the existing CUHP version results (existing MDP models) and the proposed CUHP results. Assuming they both were, it would be nice to compare how much of the reduction in peak flow is related to the reduced rainfall and how much is a result of the proposed adjustment to CUHP.

Response: These comparisons were made but not presented to keep it brief. The plots presented are from the published MDP models which used the UDFCD Rainfall. One of the original recommendations was to adopt new NOAA rainfall and apply Dynamic Wave Routing for attenuation, and make limited changes to CUHP. This recommendation was not carried forward, but still may be valid.

Rapp: There is a very slight discontinuity in the Peaking Parameter Equation at the 5% cutoff threshold. This can be seen in the attached spreadsheet. The equation produces values below 0.5 for imperviousness between 5% and 5.1%. Therefore, it is recommended that in the CUHP code, the threshold be set so that for Imperviousness <= 5.1%, P = 0.5. Above this threshold the equation can be used. I don't think it is necessary to show this level of precision in the report or user manual, but in the model it is probably best to avoid the discontinuity since these types of issues always seem to come up later for a very specific scenario.

Response: Thank you for checking, this has been corrected within the Sept. Version of the Summary Report.

Rapp: The attached spreadsheet provides a comparison between the old and new equations for P, C_p, C_T, and C_t.

a. As shown in the plots, the Peaking Parameter (P) decreases in the proposed model. This is as expected since the overall goal was to reduce peak flows.

b. The coefficient of Peaking (C_p) also decreases in the proposed model as expected.

c. The timing coefficient (C_t) for subcatchments less than 0.25 square miles also decreased in the proposed model. However, this was unexpected since smaller C_t values result in a shorter Time to Peak (T_p). This means that the resulting hydrograph will have a smaller peak but will also occur more quickly and have a long drawn out receding limb to conserve volume. This seems counterintuitive because it has the potential to further exacerbate the problem of hydrographs stacking up on each other in the routing process. In order to validate the adjustment to the timing coefficient, it is necessary to compare the resulting hydrograph shapes and peak timing at the recorded stream gages instead of just the peak flow values. Although this may have been done, as the report stands now there are no results presented to compare outflow hydrographs at the gages and to justify the smaller C_t values.

Response: Thank you for checking, this has been corrected in the Sept 2016 Version of the report and CUHP.

Rogers: It would be helpful to better explain the reasons for adjusting the Cp and Ct factors. It appears that adjustment to the Cp factor is being recommended. Why? Is this for both large and small basins? Adjustment to the Ct factor is being recommended only for small drainage basins and not large basins. An explanation and/or clarification would be helpful as to why an adjustment is needed for small basins.

Response: The peaking parameter adjustments effects basins of all sizes. Adjustments to timing for the small basins is necessary to avoid a major discontinuity at 0.25 sq miles. These have been adjusted in the Sept 2016 Version per other comments.

Morrisey: What Imperviousness was used to produce these curves? Is 5.6 cfs/ac valid, nothing less than 4 cfs/ac?

Response: 50%, the unit curve for a unit rainfall excess does not go lower than 4 cfs/ac until 0.5 sq miles, yes, that is correct.

Rapp: In most locations throughout the report, CUHP v1.4.1 is referred to as the current version of CUHP. However, the current version is 1.4.4 and it has been since September 2014, well before this recalibration study was even started. Is there a reason the study was done using v1.4.1 as opposed to 1.4.4, or is this simply a typographical error throughout the report?

Response: This is a typo, we updated all the models from the MDP planning studies to version 1.4.4 at the beginning of this study.

Anderson: Do you mean the row labeled "Average of All Storms"?

Also, i don't see any + or - signs in Table 2

Response: Table 2 column that says *this accounts for positive and negative values* shows this.

Rogers: Very few, if any, gage data is available, or was used, from tributaries west of the S. Platte River. Many of these tributaries that have had hydrology studies done in the recent past have shown higher runoff flows. Are we comfortable that this re-calibration effort will take into account the physical differences (long, narrow, steep basins) of these tributaries as opposed to the tributaries east of the S. Platte River?

Response: Out of the entire gage record, very few gages were available, however, gages west of the South Platte river were tested with frequency testing and one of the calibrated basins is West of the S Platte. We expect that the proposed version will trend better with gage frequency analysis for gages west of the S. Platte as well as across the District. Care should be taken when applying CUHP to Mountain Basins.

Urbonas: Comparing Log-Pearson analysis to current and proposed CUHP results, I do not see that the differences justify making this change in CUHP. The Enginuity report did not show confidence bands for the two CUHP models, only for the Log-Pearson analysis. But, if you give consideration to the fact that both CUHP analyses also have confidence band, you will find that all results overlap. In other words, the proposed changes are not statistically significant.

Response: There is not a method to generate 5 and 95% confidence intervals with the Unit Hydrograph Method. It is shown that the current version of CUHP mostly sits within the +/- 20% gage error that could be expected but that almost all the data sit at or above the middle line. It is agreed that this could be statistically insignificant. During the beginning of this study it was presented to the District that if our goal was to justify the current version of CUHP it could be done as the spread of the data was large, and many times the current version of CUHP was applicable, although it sits on the higher end, especially when discretized into smaller basins and routed via kinematic wave. As previously noted, this is not a new problem and many studies have been funded by the district to dampen these effects, and to date, none seemed to produce results that are having that effect in the master planning process. The do nothing alternative was not considered an option since very study is requiring the consultant to manually (and sometimes randomly) adjust the peaking and timing parameters to get different results. It was not felt that this is a good path to continue forward.

Rapp: In reviewing Table 2, and looking at the individual storms as opposed to the summary average, the proposed single basin model does not appear any better than the existing single basin model (geometric mean of Error is 24% vs. 25%). Whereas, for small basins, the proposed model does seem to provide better results. This raises concerns that the proposed model may actually underestimate peak flows in larger basins (it underestimates half of the recorded peak flows in Table 2).

Response: Yes, when modifying the curves my attempt was to make little change for the larger basins. This was based on the initial findings that large basin CUHP were producing reasonable results and the compounding of hydrographs via KW is the real problem. As such, the dampening for smaller basins was needed if attenuation and natural processes in the watershed are to be ignored. However, I was unable to generate a curve that didn't affect the larger basins and still produced results from smaller basins that sat closer to our gage analysis. This has also been adjusted in the Sept 2016 Version.

Rapp: In Figures 4 and 5, I would agree that the proposed model peak flows more closely straddle the recorded flows than the existing model. However, the proposed model also more commonly underestimates the peak flows which could be viewed as a bad thing in regard to public safety. For Goldsmith Gulch, the proposed model is below the lower confidence interval indicating that it underestimates peak flows for the 2-, 5-, and 10-year events.

Response: Yes, based on other comments, this is indeed a concern. The drop below the confidence intervals for goldsmith is due to the larger differences in NOAAs new atlas at those intervals. The lower frequency's trend very nice when the 2, 5, 10 old rainfall depths were used, however, the recent NOAA atlas drops these values more significantly than the differences at the larger interval (less frequent storms.). This has been updated in the Sept 2016 Version.

Baxter: what is the basis for separation between upper/lower storms, and why was this done?

Response: It was separated by area into an upper and lower basin, than those grids were taken and averaged to make a hyetograph for upper and lower basins. It was done because of the geographic variability and size of basin. The entire Goldsmith basin rarely sees a storm covering the entire basin as it is long, narrow, and sloping south to north.

Piza: When comparing design storms to stream gage, why not use the dynamic wave method? Wouldn't this be more accurate?

Response: Yes, I feel it would be. However, we were trying to make comparisons that reflect how the model would be applied. As such, our calibration models needed to be built and applied in the same manner that they would for a drainageway study.

Baxter: these two computed curves are clear, but what is the line labeled as "Computed Curve" ?

Response: The result from the Log Pearson III analysis that includes all outliers.

Urbonas: The Harvard Gulch at Harvard Park example illustrates something I been harping about for years, namely that the CUHP model used was misapplied and not properly routed. Especially the 1997 FHAD. Regardless, the new and the old CUHP virtually produce identical results in that example for all return periods.

Response: Thank you for your comment and highlighting the effects of the Canal. The Sept. 2016 Report has updated language and figures.

Anderson: Please explain possible reasons that both the blue and orange lines are outside the confidence limits, applicability of this to the overall study and why/whether it should be included or disregarded.

Response: Many anthropologic development effects the gage readings, the canal, the culvert backwater downstream of the gage, differences in vegetation development, and also the large stormsewer down Yale.

Knowing this, our goal was to reach the higher confidence intervals for trusted gages to maintain a level of conservatism in hydrologic practice across the District.

Morrisey: Would it be worth checking an uncalibrated CUHP 1.4.4 for the sake of comparison to the Proposed CUHP? The MDP results represent better correlation with gage data. The Proposed CUHP results are substantially higher than gage data.

Response: We have made that comparison, and included it within the most recent report.

Morrisey: Are the flows presented in the graph unaltered from WC MDP, or modified per steps listed below?

Response: That particular graph is the original flows from the WC MDP that includes all the alteration they applied for calibration.

Rogers: Does this mean that actual flow at this gage was not measured, or that gage data is not available? What is the difference between the "Predicted Flow from Gage Analysis" and "Computed Curve"?

Response: It is the same as computed curve, will modify to be consistent. Thank you for the catch.

Urbonas: What I like to point out is that the North Sanderson Gulch data are very suspect. When we analyzed the date many years back, we found that it did not follow typical unit peak discharge trends. Upon field investigations, we found that the major storm sewer upstream of the gage had no stormwater inlets and that the flows at the upstream end of the catchment were greatly restricted by a culvert under a highway and detention storage. I do not know if any of these physical conditions were modified since, but these physical anomalies were there when data were taken.

Response: Thank you for pointing that out. I did not know that.

RESPONSE TO SOME OF THE CONCLUSION REMARKS:

Urbonas: My bottom line recommendation is to not modify the current CUHP Ct and Cp protocols. Instead, I recommend UDFCD focus on guiding its consultants (and ones working for developers and local governments) in setting up routing models (i.e., SWMM) properly to do a more credible job in routing small sub-catchment hydrographs through the systems. One aspect of this that needs attention is the tendency of SWMM users to not account for the effective longitudinal slopes of channels (sometimes pipes) in most reaches and merely to enter the starting and ending invert elevations at the junctures. This we found to result in excessively high peaks when small sub-catchments are used and routed using SWMM. Another, is to use very simplified cross-sections, sometimes ones that have much less flow storage that woule be available if more representative ones were used. Also, I observed that many of the routings in the past ignored the recommendations in the USDCM to increase the Manning's *n* by around 25% in order to reduce the tendency to over-accelerate the flows in the system, something that contributes to higher peaks downstream. Mathematically defined routing elements, do not have the imperfections that real-works routing elements have and users of SWMM need to compensate for this, namely by increasing their roughness.

As to changes in the NOAA rainfall used, they too will have a ripple effect on all past studies. Although, the changes are not significant in most places within UDFCD, personally I am not convinced the end result of this change is fully justified for UDFC.

Response: We fully understand the routing concern and made updates to the Sept Version of the Report. We also considered many different alternatives during this study. Currently, every study requires the user to adjust Cp and Ct in addition to the routing you discuss above. It sounds like you feel this is acceptable as a permanent path forward and the District requested a different option than status quo. Discussing comments and cross sections and flow storage: The math in the kinematic wave does not account for flow storage or attenuation and as such will have minimal impact.

Rapp: The biggest concern with the re-calibration approach is that there does not appear to be any comparison of peak timing with the gage results. The modifications to the equations are changing the timing of the hydrograph peaks as well as the peak value. Plots should be created to show the outflow hydrographs from the existing and proposed CUHP/SWMM models and then compare those with the recorded stream gauge data to see how well the timing matches up. This will show what effect the reduced time to peak has in combination with the SWMM routing network.

Response: We have compared the timing and they match well. The Sept 2016 Version Addresses these comments.

Rapp: There also does not appear to be any evaluation of the effects of the SWMM model on the overall results. This may have been performed but is not discussed or presented in the report. As shown in Table 2, the proposed model still has a noticeable increase in peak discharges for Upper Harvard Gulch and Little Dry Creek when going from a single large basin to several small basins. This indicates that the routing network results in increased flows using the shorter time to peak from the individual subcatchments. However, the flows decrease for Goldsmith Gulch and remain relatively constant for Dutch Creek. This indicates that the SWMM routing does play a significant role in the overall peak flows and unit discharges for a watershed. The timing of the individual hydrographs and how quickly they are routed and combined in the drainage network are significant when comparing to a recorded gage downstream. To ignore the time to peak of the hydrograph and the interconnectivity of the subcatchments within the routing network and simply reduce all subcatchment peak discharges so that the net effect at the downstream end of a few watersheds have an average peak flow closer to the recorded gages does not seem sufficient. On the other hand, if these factors were considered in the re-calibration then the results should be presented in the report.

Response: The Sept 2016 Report has been adjusted based on these comments.